2003

Three essays on welfare implications of R&D policies in the presence of spillovers

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Three essays on welfare implications of R&D policies

in the presence of spillovers

by

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A dissertation submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY

Major: Economics

Program of Study Committee:
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Iowa State University
Ames, Iowa
2003

UMI Number: 3085923

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Major Professor

Signature was redacted for privacy.

For the Major Program

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ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Harvey E. Lapan, for his guidance and patience throughout this research. His numerous suggestions and comments have been always helpful. It has been an enriching and enjoyable experience for me to complete this dissertation under his supervision. Without his advice and interests, this dissertation could never have been completed.

Thanks are also due to my committee members, Dr. Choi, Dr. Moschini, Dr. Schroeter, and Dr. Meeker for providing helpful suggestions while serving on my dissertation committee. I am grateful to the faculty and the staff of the department of economics for the help I received during my graduate study. Special thanks go to Dr. Kilkenny for her financial support and encouragement during my studies.

I would like to express my deep appreciation to my parents for their understandings and support during the preparation of this dissertation. I also thank to my sister and brothers for their encouragement.

Finally, I am grateful to my wife, Yang-Hee, and my kids, Soh-Yeon and Min-Jae, for their love and support throughout my graduate study.

ABSTRACT

This dissertation consists of three essays investigating welfare implications of R&D policies in the presence of spillovers. Unlike previous studies, it focuses on modeling endogenous or asymmetric spillovers to obtain more practical welfare implications. Each essay introduces a representative 'R&D model with spillovers'. The game we consider in each essay is basically composed of two stages: the R&D stage and the output stage. Each essay identifies the Subgame Perfect Nash Equilibrium (SPNE), and provides meaningful policy implications in terms of welfare.

The first essay examines the policy implications of a research joint venture (RJV) while introducing endogenous spillovers and costly RJV. The research joint venture is costly in the sense that the firms incur two kinds of costs when they join in an RJV: RJV formation costs and spillover costs. RJV formation costs are modeled as fixed while spillover costs increase with the amounts of information sharing within an RJV. We derive the condition under which firms do not have an incentive to form an RJV, and identify when firms within an RJV share information completely. This essay also finds that private interests with an RJV are not consistent with public interests for a wide range of RJV formation costs, which suggests the potential need for active government intervention with respect to RJV formation.

The second essay investigates the welfare effects of intellectual property rights (IPR) protection in terms of north-south trade. It asks which southern countries, if any, should provide more IPR protection, assuming that the differentiated IPR protection among southern countries can be made through a WTO (World Trade Organization) agreement. Only the northern country innovates, and n-1 southern countries have different capacities to absorb knowledge from the northern innovations. The outcome of innovations reduces the unit production cost of the northern firm, and also provides benefits to the southern firms through spillovers. This essay shows that the southern countries can be classified into three groups in terms of the welfare effects of spillovers. The countries in the first group are better off from relaxed IPR protection both in their own countries and in the other countries. The countries in the second group are better off from spillovers in their country, but worse off from spillovers in the other group. The third group suffers from welfare loss whenever IPR protection is relaxed in any southern country. The northern country is worse off by relaxed

IPR protection in any southern country for wide ranges of R&D efficiency and the sum of spillovers.

The last essay combines the analysis of the R&D cooperation with the strategic trade policy theory. Endogenizing spillovers (information sharing) within an RJV, it identifies when the RJV works as a tool of strategic trade policy, and provides its welfare implications. Many results obtained in the third market structure become reversed in the integrated market structure. In the situation where only the home country allows an RJV formation while the foreign country does not, allowing an RJV benefits the home country in the third market structure, but it hurts the home country in the case of integrated market structure if spillover costs are sufficiently high. We also identify the Nash equilibria of the policy game in which both the home and the foreign countries simultaneously decide whether to allow an RJV or not, and investigate the welfare implications when both the home and the foreign countries allow an RJV formation in each country.

CHAPTER 1. GENERAL INTRODUCTION

1.1 Introduction

The outcome of research and development (R&D) activities is usually interpreted as a piece of new knowledge or information. Because the knowledge has basically the nature of a public good, the use of new knowledge by one agent does not exclude its use by another, and the innovators cannot keep non-payers from using it.[1] Consequently, innovators are not likely to recover the full value that they generate from the research outcomes, and this undermines the incentive to do R&D. One well-known way to deal with this problem is providing innovators with intellectual property rights (IPR) in the form of a patent. However, as many empirical studies have documented, patents do not always prevent knowledge spillovers to rival competitors (see Mansfield et al. 1985, Jaffe 1986, Levin et al. 1987). Griliches summarizes one common result of empirical studies as follows: "R&D spillovers are present, their magnitude may be quite large and social rates of return remain significantly above private rates" (see Griliches (1995), p72).

The theoretical literature has paid considerable attention to the encouragement of R&D cooperation or the formation of a research joint venture (RJV) as a way to internalize spillovers.[2] It generally investigates the relative efficiencies of R&D competition and cooperation in raising final output production and enhancing social welfare.[3] A consistent finding is that the R&D cooperation may increase a firm's incentive to invest in R&D by internalizing spillovers. One more important result is that research joint ventures (RJVs) may result in the highest R&D outcome, output production, and welfare level if firms within an RJV can share information completely (see Kamien et al. 1992)

However, there are some limitations to the theoretical literature dealing with spillovers. First, it usually assumes that spillovers are exogenously given and beyond the

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[1] For a summary of this issue, see Geroski (1995).
[2] One concern of R&D cooperation is that cooperation may extend to the product market (Jacquemin 1988)
[3] Among seminal papers are Spence (1984), d'Aspremont and Jacquemin (1988), Kamien et al. (1992), Suzumura (1992), Simpson and Vornortas (1994), and Ziss (1944).

controls of firms.[4] Some treat spillovers (information sharing) within an RJV (or R&D cooperation) as the same as in the case without the RJV, while others assume maximal spillovers within an RJV. As Cohen and Levinthal (1989) argue, however, the degree of spillovers that each firm obtains from the other's innovations may be different across firms, depending on its ability to assimilate or absorb knowledge spillovers. It may also depend on how much each firm discloses its knowledge to the other. A number of factors, such as the degree of final market competition and technical substitutability, will affect each firm's disclosure of its knowledge.

Second, the literature assumes that there are no obstacles when firms form an RJV and share information with each other. However, in a real economy, firms face many difficulties and costs associated with RJV formation and information sharing. As Pérez-Castrillo and Sandonís (1996) argue, potentially profitable RJVs may not start because of the moral hazard problem between the partners. Also, the potential costs associated with forming an RJV will be large and may include contracting, monitoring, and management costs (see Harrigan (1986)). These costs are likely to increase, as the firm wants to share more information from the others. Finally, the issue of 'asymmetric spillovers' has rarely been studied in the theoretical R&D literature.[5] In general, however, firms may differ in their absorptive capacities due to already existing differences in the knowledge base and organizational firm characteristics. Also, the degree of spillovers may be different across industries, depending on whether the industry is more R&D intensive or not (Levin et al. 1987). Thus, it seems unrealistic to assume that all firms are identical in absorbing or assimilating knowledge spillovers.

It is clear that more studies on endogenous and asymmetric spillovers are necessary as there are few previous studies on these issues, and we may get more practical policy implications from them. This dissertation introduces endogenous or asymmetric spillovers into a representative two-stage 'R&D model with spillovers'. The main purpose is to

[4] Some previous studies dealing with endogenous spillovers within an RJV are reviewed in chapter 3.
[5] The exceptions are Rosen (1991), De Bondt and Henriques (1995), and Amir and Wooders (1999).

investigate the welfare implications of two R&D policies: encouraging RJV formation and tightening intellectual property rights.[6]

1.2 Dissertation organization

Chapter 2 investigates policy implications of a research joint venture (RJV) while introducing endogenous spillovers and costly RJV. We derive the condition under which firms do not have an incentive to form an RJV, and identify when firms within an RJV share information completely. We find that private interests with an RJV are not consistent with public interests for a wide range of parameter values, and suggest the potential need for active government intervention on RJV formation. Chapter 3 introduces spillovers into the issue of intellectual property rights (IPR) in the context of north-south trade. Assuming southern countries face different spillovers, we ask which countries, if any, should provide more IPR protection. We investigate how spillovers from relaxed IPR protection in any southern country affect its welfare and welfare in the other countries. Chapter 4 combines the analysis of the R&D cooperation with strategic trade policy theory. Endogenizing spillovers (information sharing) within an RJV, it identifies when the RJV works as a tool of strategic trade policy, and provides its welfare implications. The last chapter provides general conclusions and discusses future areas of research.

[6] For more detailed explanation of these policies, see Katz and Ordover (1990). Katz and Ordover term these policies as ex-ante cooperation and ex-post cooperation, respectively.

CHAPTER 2. ENDOGENOUS SPILLOVERS AND COSTLY RESEARCH JOINT VENTURE

2.1 Introduction

The previous studies on R&D, spillovers, and RJV (research joint venture) focus on examining the role of spillovers (information sharing) in comparing outcomes between the R&D non-cooperation and the cooperation game (See De Bondt (1996) for a detailed survey). These studies usually treat spillovers as exogenous and beyond the control of firms regardless of the RJV (or R&D cooperation) existence.[1] A consistent finding is that the R&D cooperation may result in better outcome especially when spillover parameter has sufficiently high value. However, as Katz (1986), Katsoulacos and Ulph (1998), and Poyago-Theotoky (1999) pointed out, it seems unreasonable to assume that spillovers within an RJV are exogenously given when we want to investigate the effect of RJV on economic performance.

This chapter examines the policy implications of an RJV on total welfare. There are two specific contributions of this chapter. First, we introduce endogenous spillovers within an RJV into d'Aspremont and Jacquemin's model (1988). Few studies have dealt with endogenous spillovers within an RJV. Firms may be different in their ability to absorb or assimilate knowledge spillovers (Cohen and Levinthal (1989). Also, a number of factors, such as the degree of market competition and the nature of research discoveries, may affect the amount by which the firms benefit through spillovers. The other specific contribution is that we model costly RJV. The potential costs associated with forming an RJV will be large, and may include contracting, monitoring, and management costs (Harrigan (1986)). We assume that both RJV formation and spillovers are costly.[2]

Assuming Cournot competition with a single homogenous good in a final market, we find that firms under the RJV do not share any information if spillover costs are sufficiently high. It is also shown that private interests with an RJV are not consistent with

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[1] For example, see d'Aspremont and Jacquemin (1988) and Kamien et al. (1992)

[2] Vilasuso and Frascatore (2000) introduces costly RJV. However, they do not endogenize spillovers within an RJV even though they consider a case where firms under the RJV face the cost, which depends on the degree of spillovers.

public interests for a wide range, which suggests the potential need for active government intervention on RJV. To obtain these results, RJV formation costs, spillover costs, and involuntary spillovers play a crucial role.

The main policy implications are as follows. First, if spillover costs are sufficiently high but the degree of involuntary spillovers is sufficiently low, then the government should discourage firms from joining in an RJV if RJV formation costs are relatively low. However, it does not have to implement any policy for relatively high RJV formation costs since private and public interests are consistent. Second, if both spillover costs and the degree of involuntary spillovers are sufficiently high, then government intervention is unnecessary for very low or very high RJV formation costs, while it should encourage firms to join in an RJV for median RJV formation costs. Finally, when spillover costs are sufficiently low, the same results as in the second case are obtained, but it is shown that the critical value of RJV formation costs is different.

This chapter is organized as follows. Section 2 provides a literature review on spillovers and RJV. Section 3 sets up the model and examines possible equilibria. Section 4 focuses on welfare comparisons, and policy implications on RJV are addressed in section 5. The last section provides concluding remarks.

2.2 Literature Review

Most of the R&D literature deals with spillovers as exogenous and beyond the control of firms. Some papers treat spillovers (information sharing) within an RJV as the same as those that occur when there is no RJV, while others assume that maximal spillovers occur within an RJV. For example, in d'Aspremont and Jacquemin (1988), firms face the same spillovers with R&D cooperation as in the R&D non-cooperation game. Meanwhile Kamien et al. (1992) assume that the RJV can achieve complete information sharing. However, if we want to understand the effect of an RJV on innovative or economic performance, it seems reasonable to assume that spillovers are determined endogenously within an RJV.

Three theoretical works, Katz (1986), Katsoulacos and Ulph (1998), and Poyago-Theotoky (1999), consider the R&D cooperation game where the firms choose spillovers (information sharing). Katz (1986) considers only the case of complementary research outcomes. The technology that one firm discovers, therefore, is always beneficial to the rival firm if the rival firm can absorb it through spillovers. Katsoulacos and Ulph (1998) examine a number of factors that need to be considered when the spillovers are treated as endogenous. For example, the amount that the firms benefit through spillovers may be restricted, depending on whether firms operate in the same industry or in different industries and whether the research discoveries are technical substitutes or complements.[3] Poyago-Theotoky (1999) extends d'Aspremont and Jacquemin's model by allowing firms to choose spillovers in both the R&D cooperation and the non-cooperation games.

One common result of these works is that firms under the RJV choose maximal spillovers in the case where firms compete with a homogenous good in a final market. This result has to be reexamined since it is obtained by ignoring the fact that firms in a real economy face many difficulties and costs when they form an RJV, and when they absorb other firm's information or transfer their knowledge to other firms. The difficulties may be related to the moral hazard problem between the partners of a RJV in the sense that it is very difficult to impose the transfer of technology by contract. Pérez-Castrillo and Sandonís (1996) examine this problem and they show that because of this moral hazard problem, potentially profitable RJVs sometimes do not even start. Meanwhile, Vilasuso and Frascatore (2000) show, by introducing costly RJV, that the interests of firms are not necessarily consistent with social interests. They argue that the government should encourage R&D competition rather than the RJV (R&D cooperation) if forming an RJV is very costly.

We extend previous studies mentioned above by simultaneously considering two issues: endogenous spillovers and costly RJV. In this sense, our model is a combination of the Poyago-Theotoky's model (1999) with that of Vilasuso and Frascatore (2000). Poyago-Theotoky introduces endogenous spillovers into d'Aspremont and Jacquemin's model, but she does not consider any cost when firms form an RJV or when firms increase the

[3] If research discoveries are pure technical substitutes, then neither firm can benefit from a rival firm's knowledge discovery (for more detail, see Katsoulacos and Ulph (1998)).

information sharing. Vilasuso and Frascatore do not endogenize spillovers even though they consider the case in which firms under the RJV face a cost, which depends on the degree of spillovers (see Table 1. The spillover parameter, β, is not a choice variable in their paper).

Table 2.1 Summary of the literature on 'information sharing' under RJV[4]

	Spillovers		Costly RJV	Conclusion
	(W/O RJV)	(With RJV)		
Katz (1986)	Exogenous Symmetric	Endogenous ($\beta = 1$)	No	The RJV has socially beneficial effects when there are spillovers in the absence of cooperation
D'Aspremont & Jacquemin (1988)	Exogenous Symmetric	Exogenous No change	No	R&D cooperation results in better outcome than R&D competition for sufficiently high spillovers
Kamien et al. (1992)	Exogenous Symmetric	Exogenous ($\beta = 1$)	No	RJV($\beta = 1$) may result in best outcome
Katsoulacos & Ulph (1998)[5]	Endogenous ($\beta = 0$)	Endogenous ($\beta = 1$, $0 < \beta < 1$)	No	Under RJV, the firms may choose the maximal or the non-maximal spillovers
Poyago-Theotoky (1999)	Endogenous ($\beta = 0$)	Endogenous ($\beta = 1$)	No	Under RJV, the firms choose the maximal spillovers. RJV results in better outcome.
Vilasuso & Frascatore (2000)	Exogenous Symmetric	Exogenous ($\beta = 1$)	Yes $F = k$ $F = k + \phi\beta$	The interests of firms are not necessarily consistent with social interests if RJV is costly

[4] $\beta = 0$ and $\beta = 1$ denote minimal and maximal spillovers, respectively.

[5] For the process innovation and Cournot competition, firms in an RJV choose the maximal spillovers while they choose non-maximal spillovers for the product innovation and Bertrand competition.

2.3 The Model and Equilibrium

2.3.1 The Model

In a final market, two firms sell a homogenous product whose inverse demand is given by $P = A - Q$, where $Q = q_i + q_j$, $i, j = 1,2$, $i \neq j$. q_i represent the final output of firm *i*. Firm *i*'s unit production cost is a function of its own R&D investment (χ_i), the rival firm's R&D investment, and spillovers so that it is written by

(1) $C_i = c - \chi_i - \sigma_i \chi_j$, $0 \leq \sigma_i = \theta + \beta_i \leq 1$, $i, j = 1,2$, $i \neq j$.

The spillover parameter, σ, is separated into two terms, industry-wide involuntary spillovers, $\theta \in [0,1]$, and a firm-specific spillover parameter, $\beta \in [0, 1-\theta]$. The magnitude of involuntary spillovers may depend on the degree of the intellectual property right (IPR) protection. For example, if IPR protection is perfect, then there may not be involuntary spillovers in the economy, i.e., $\theta = 0$.[6] As in Cohen and Levinthal (1989), the term of the firm specific spillover, β, may reflect a firm's ability to absorb or assimilate its rival firm's knowledge.[7] We assume that the degree of spillovers from which a firm benefits is determined by this ability as well as involuntary spillovers.[8]

The R&D technology exhibits diminishing returns to scale to R&D investment so that its cost is written by $TC_i(\chi_i) = \gamma \chi_i^2 / 2$ where γ denotes R&D efficiency. A higher γ implies lower R&D efficiency.[9] The main assumption is that firms face two kinds of costs: RJV formation cost and spillover cost. If firms decide to join in an RJV, then they incur a fixed cost (*F*) as the fee for starting the RJV. Besides this cost, each firm that absorbs the rival firm's knowledge should incur other costs, which depend on the amount of information

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[6] This is the case in Poyago-Theotoky (1999).

[7] Cohen and Levinthal call this ability 'absorptive capacity'. They take the form of spillover parameter as $\sigma_i = \theta \beta_i$.

[8] Contrary to our set-up, in Poyago-Theotoky spillovers totally depend on the rival firm's voluntary knowledge transmission. Thus, the unit cost function is in the form of $C_i = c - \chi_i - \sigma_j \chi_j$. This specification will not qualitatively change any result obtained from this chapter.

[9] In d'Aspremont and Jacquemin's model, γ may play an important role in the sense that both the second order and the stability condition depend on this parameter.

sharing.[10] We assume that this cost increases with the amount of knowledge absorbed. For example, if each firm wants to absorb more knowledge from the rival firm, then it may have to send more researchers to the research joint venture. We refer to this cost as spillover (or information sharing) cost, which is given by $K_i = k\beta_i$, $i = 1,2$.

In the R&D non-cooperation game two firms simultaneously choose R&D efforts in the first stage and face Cournot competition in the second stage. We assume that the firms cannot choose the spillovers in the R&D non-cooperation game.[11] Thus, the firms under the R&D competition face only involuntary spillovers ($\sigma_i = \theta$). In the R&D cooperation game, firms decide whether to join in an RJV or not in the first stage. If they decide to join in a RJV, then they incur a fixed cost (F) as the fee for starting an RJV. Firms also choose both R&D efforts and the degree of information sharing to maximize joint profits in the first stage[12] while they face output competition in the second stage. Note we assume the decision of joining in an RJV, and choosing both R&D investment and spillovers is taken together in the first stage.[13]

2.3.2 Equilibrium

The nature of the equilibrium is subgame perfect Nash equilibrium. To find out the equilibrium, we first solve for the Nash equilibrium in the final market and then work backwards, solving for the R&D levels. In the final stage, each firm chooses quantity to maximize its own profits given the previous stage R&D investment. Firm *i*'s final stage profits are as follows: $\pi_i = (A - Q)q_i - C_i q_i$

[10] Vilasuso and Frascatore (2000) consider an RJV formation cost that depends on the spillover amount ($K = F + k\beta$), even though they do not make spillovers endogenous.

[11] Introducing endogenous spillovers into this game leads to the different result than in Poyago-Theotoky, in which the firms choose the minimal spillovers. With our set-up of spillovers, even firms under the R&D non-cooperation game will choose maximal spillovers assuming there is no cost in doing that.

[12] We follow the assumption of joint profit maximation as the standard in the literature in the sense that the literature has uniformly assumed the joint profit maximization under the RJV. However, whether this assumption is appropriate requires further analysis since it is difficult to believe that firms, in reality, can write the contracts to maximize joint profits when they are competitors in a final market. Also, there may be firms' incentive to deviate from joint profit maximization. For example, if firm's profit is a portion of total profits under the RJV and the portion depends on its own R&D spending then it may be more profitable for the firm to deviate by maximizing its own profit choosing own R&D spending. Salant and Shaffer(1998) and Anbarci et al.(2002) briefly mention this issue.

[13] R&D cooperation game may consist of a three-stage game without changing any results obtained here.

Solving the problem yields final stage output and profit as a function of R&D investment and spillovers:

(2) $q_i^* = \dfrac{A-2C_i+C_j}{3} = \dfrac{A-c+(2-\sigma_j)\chi_i+(2\sigma_i-1)\chi_j}{3}$, $\pi_i^* = (q_i^*)^2$, $i \neq j$, $i = 1,2$.

2.3.2.1 Non-cooperative R&D competition

In the first stage, each firm chooses the level of R&D investments to maximize its own profit, which is written by

(3) $V_i = \pi_i^* - TC_i(\chi_i) = \dfrac{\{A-c+(2-\theta)\chi_i+(2\theta-1)\chi_j\}^2}{9} - \dfrac{\gamma}{2}\chi_i^2$, $i \neq j$, $i = 1,2$.

The first and second order conditions are as follows:

(4) $\dfrac{\partial V_i}{\partial \chi_i} = \dfrac{2\{A-c+(2-\theta)\chi_i+(2\theta-1)\chi_j\}(2-\theta)}{9} - \gamma\chi_i = 0$, $i \neq j$, $i = 1,2$.

(5) $\dfrac{\partial^2 V}{\partial \chi_i^2} = \dfrac{2(2-\theta)^2}{9} - \gamma < 0$, $i = 1,2$. This holds for $\forall\theta$ if $\gamma > \dfrac{8}{9}$.

From the first order condition, assuming a symmetric solution ($\chi_i = \chi_j = \chi$), we can get the equilibrium R&D investment: $\chi^N = \dfrac{2(A-c)(2-\theta)}{9\gamma - 2(1+\theta)(2-\theta)}$. As seen in Henriques (1990), the equilibrium R&D investment under the non-cooperative game may not be stable for sufficiently low involuntary spillovers even though the second order condition is satisfied. She used the stability condition[14], $|\partial\chi_i/\partial\chi_j| < 1$, which yields in our set-up:

$\left|\dfrac{\partial\chi_i}{\partial\chi_j}\right| = \left|\dfrac{\partial^2 V_i/\partial\chi_i\partial\chi_j}{\partial^2 V_i/\partial\chi_i^2}\right| = \left|\dfrac{2(2-\theta)(2\theta-1)}{2(2-\theta)^2 - 9\gamma}\right| < 1 \Leftrightarrow \gamma > \dfrac{12}{9}$ for $0 \leq \theta \leq 1$. Since the second order condition for an interior solution of R&D investment under R&D competition is $\gamma > 8/9$ for $0 \leq \theta \leq 1$, the equilibrium R&D investment may not be stable if the degree of R&D efficiency lies between 8/9 and 12/9, i.e., $8/9 < \gamma < 12/9$. If the equilibrium is unstable, we may have to consider a corner solution where only one firm invests in R&D under the R&D

[14] When this condition is satisfied, the non-cooperative outcome is stable in the sense that the reaction functions cross "correctly" in the R&D space (See Henriques).

non-cooperation game. Since this is not what we want to focus on in this chapter, we impose $\gamma > 12/9$ throughout this chapter. Finally, using the equilibrium R&D investment yields the following outcomes, where N denotes the R&D non-cooperation game, and W denotes total welfare.

$$\chi^N = \frac{2(A-c)(2-\theta)}{9\gamma - 2(1+\theta)(2-\theta)},\ q^N = \frac{3\gamma(A-c)}{9\gamma - 2(1+\theta)(2-\theta)},\ Q^N = \frac{6\gamma(A-c)}{9\gamma - 2(1+\theta)(2-\theta)}$$

$$V^N = \frac{\gamma(A-c)^2\{9\gamma - 2(2-\theta)^2\}}{\{9\gamma - 2(1+\theta)(2-\theta)\}^2},\ W^N = \frac{4\gamma(A-c)^2\{9\gamma - (2-\theta)^2\}}{\{9\gamma - 2(1+\theta)(2-\theta)\}^2}$$

2.3.3.2 Cooperative R&D competition (Research Joint Venture)

The final stage profits for each firm are given by equation (2). In the first stage, the firms under the RJV maximize their joint profits while choosing the R&D investment and the amount of information sharing (β_i). The firms incur RJV formation cost (F) and spillover cost ($k\beta_i$). The joint profit function can be written by

$$(6)\ V^J = \frac{1}{9}[\{A-c+(2-\sigma_j)\chi_i+(2\sigma_i-1)\chi_j\}^2+\{A-c+(2-\sigma_i)\chi_j+(2\sigma_j-1)\chi_i\}^2]$$
$$-\{(\gamma\chi_i^2+\gamma\chi_j^2)/2\}-\{k\beta_i+k\beta_j\}-2F,\ i\neq j,\ i=1,2.$$

where V^J denotes the joint profit under the RJV.[15]

The first order conditions for joint profit maximization are

$$(7)\ \frac{\partial V^J}{\partial \beta_i} = \frac{2}{9}[\{A-c+(2-\sigma_j)\chi_i+(2\sigma_i-1)\chi_j\}(2\chi_j)+$$
$$\{A-c+(2-\sigma_i)\chi_j+(2\sigma_j-1)\chi_i\}(-\chi_j)]-k=0,\ i\neq j,\ i=1,2.$$

$$\frac{\partial V^J}{\partial \chi_i} = \frac{2}{9}[\{A-c+(2-\sigma_j)\chi_i+(2\sigma_i-1)\chi_j\}(2-\sigma_j)+$$
$$\{A-c+(2-\sigma_i)\chi_j+(2\sigma_j-1)\chi_i\}(2\sigma_j-1)]-\gamma\chi_i=0,\ i\neq j,\ i=1,2.$$

The second order conditions are: for $i\neq j$, $i=1,2$

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[15] Thus, the final per firm profit under the RJV is denoted by $V^J/2$

(8) $\frac{\partial^2 V^J}{\partial \beta_i^2} = \frac{10}{9}\chi_j^2 > 0$, $\frac{\partial^2 V^J}{\partial \chi_i^2} = \frac{2}{9}\{(2-\sigma_j)^2 + (2\sigma_j - 1)^2\} - \gamma < 0$ for $0 \le \sigma_i, \sigma_j \le 1$ if $\gamma > \frac{10}{9}$

Assuming that R&D investment and spillovers are determined together, we can solve the problem. From the second order condition with respect to spillovers, we should consider a corner solution ($\beta_i = \beta_j = \beta = 0$ or $\beta_i = \beta_j = \beta = 1-\theta$). That is, the firms under the RJV will choose the minimal or maximal spillovers. This is confirmed from the fact that Hessian matrix of spillovers is positive definite. That is, $H_{kk}^{\beta} \equiv \partial^2 V/\partial \beta_k^2 > 0$, $k = i, j$, and $|H^{\beta}| = \frac{4}{9}\chi_i^2 \chi_j^2 > 0$ where $H^{\beta} = \begin{bmatrix} \partial^2 V/\partial \beta_i^2, \partial^2 V/\partial \beta_i \partial \beta_j \\ \partial^2 V/\partial \beta_j \partial \beta_i, \partial^2 V/\partial \beta_j^2 \end{bmatrix}$. Meanwhile, we can have a symmetric interior solution for R&D investment from (7) and (8).[16]

(9) $\chi = \frac{2(A-c)(1+\theta)}{9\gamma - 2(1+\theta)^2}$ if $\beta_i = \beta_j = \beta = 0$, $\chi = \frac{4(A-c)}{9\gamma - 8}$ if $\beta_i = \beta_j = \beta = 1-\theta$

As pointed out by Salant and Shaffer (1998, 1999), we may have to consider the asymmetric outcome of R&D investment. They show that for sufficiently low involuntary spillovers, the symmetric solution may not be optimal under R&D cooperation even though the firms are ex-ante identical. The point of Salant and Shaffer is that the asymmetric R&D investment results in lower aggregate production costs while it yields higher R&D costs compared to the symmetric R&D investment. Thus, asymmetric R&D investment may be optimal if the former effect dominates. However, the result obtained by Salant and Shaffer does not hold in our set-up. This is because we consider the case where the firms under the RJV choose the amounts of information sharing, and incur costs in doing so. With the same way as in Salant and Shaffer, we can derive the condition that the asymmetric R&D investment under the R&D cooperation may be optimal as follows:[17]

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[16] Hessian matrix of R&D investment, $H^{\chi} = \begin{bmatrix} \partial^2 V^J/\partial \chi_i^2, \partial^2 V^J/\partial \chi_i \chi_j \\ \partial^2 V^J/\partial \chi_j \chi_i, \partial^2 V^J/\partial \chi_j^2 \end{bmatrix}$, is negative definite, i.e., $H_{kk}^{\chi} < 0$ and $|H^{\chi}| = \gamma^2 - \frac{4\gamma}{9}\{(2-\sigma)^2 + (2\sigma - 1)^2\} + 4(1-\sigma)^4 > 0$ for $0 \le \sigma \le 1$ if $\gamma > \frac{10}{9}$.

[17] The same condition in Salant and Shaffer is $b\gamma < 2(1-\theta)^2$ where b denotes the substitutability of product. Since b=1 in our set-up, the condition is equivalent to $\gamma < 2(1-\theta)^2$, which is less than 2 for $\theta \in [0,1]$.

$$(10)\ \gamma < \frac{(3-\sigma_j-2\sigma_i)^2+(\sigma_i+2\sigma_j-3)^2}{9} \equiv \gamma^a$$

The condition in Equation (10) should satisfy the second order condition or stability condition[18] we consider in this chapter, i.e., $\gamma > 12/9$. Recall that we get a corner solution of spillovers, that is, $\beta_k = 0$ or $\beta_k = 1-\theta$, $k = i, j$. Also, note that asymmetric R&D investment (spillovers) should be excluded for symmetric spillovers (R&D investment) since it does not satisfy the first order condition of the joint profit maximization problem. Therefore, if asymmetric R&D investment could be optimal, one firm under the RJV should choose minimal spillovers (e.g., $\beta_i = 0$) given that the other firm could choose maximal spillovers (e.g., $\beta_j = 1-\theta$). Then, from Equation (10), we get $\gamma^a = 5(\theta-1)^2/9$, which is always less than $12/9$. This implies that asymmetric R&D investment cannot be optimal under the restriction of R&D efficiency we assume in this chapter.[19] In sum, we consider two symmetric solutions of spillovers and R&D investment as the outcomes under the RJV. For each case, we get the following outcomes:

Case MAX ($\beta_i = \beta_j = 1-\theta$): $\chi^{MAX} = \dfrac{4(A-c)}{9\gamma-8}$, $q^{MAX} = \dfrac{3\gamma(A-c)}{9\gamma-8}$, $Q^{MAX} = \dfrac{6\gamma(A-c)}{9\gamma-8}$

$$V^{MAX} = \frac{2\gamma(A-c)^2}{9\gamma-8} - 2k(1-\theta),\ W^{MAX} = \frac{4\gamma(A-c)^2(9\gamma-4)}{(9\gamma-8)^2} - 2k(1-\theta)$$

Case MIN ($\beta_i = \beta_j = 0$): $\chi^{MIN} = \dfrac{2(A-c)(1+\theta)}{9\gamma-2(1+\theta)^2}$, $q^{MIN} = \dfrac{3\gamma(A-c)}{9\gamma-2(1+\theta)^2}$, $Q^{MIN} = \dfrac{6\gamma(A-c)}{9\gamma-2(1+\theta)^2}$

$$V^{MIN} = \frac{2\gamma(A-c)^2}{9\gamma-2(1+\theta)^2},\ W^{MIN} = \frac{4\gamma(A-c)^2\{9\gamma-(1+\theta)^2\}}{\{9\gamma-2(1+\theta)^2\}^2}$$

[18] In Salant and Shaffer, there exists a range of R&D efficiency and involuntary spillovers, for which both the condition for asymmetric solutions and the second order (or stability) condition are satisfied. See Fig. 1 on pp197 of their article.

[19] There is one thing to note. It is intuitively obvious that strong diminishing returns to scale to R&D investment may exclude asymmetric solutions as an optimal equilibrium. This is true if R&D efficiency parameter, γ, is greater than 2 even when we do not consider endogenous spillovers.

We can identify when each case can occur as an equilibrium by comparing joint profits between Case MAX and Case MIN: V^{MAX} and V^{MIN}. The profit of the firm within an RJV is bigger (smaller) under Case MAX than under Case MIN only if spillover costs are sufficiently low (high), i.e., $V^{MIN} >=< V^{MAX}$ iff $k >=< k^c \equiv \dfrac{2\gamma(A-c)^2\{4-(1+\theta)^2\}}{(9\gamma-8)(1-\theta)\{9\gamma-2(1+\theta)^2\}}$. Thus, the firms under the RJV choose minimal spillovers for sufficiently high spillover costs. This is a different result from previous studies where they find that the firms always share information completely within an RJV.[20] The intuition is that the firms under the RJV always choose maximal spillovers without spillover costs since the increased output by sharing information completely has a dominant effect on profits. However, if spillover costs are sufficiently high the firms under the RJV do not have an incentive to share information because spillover costs affect profits negatively.

It is straightforward to show that without RJV formation costs (F=0), the firms prefer joining in an RJV because profits are always bigger under the RJV than under the R&D non-cooperation. This result is intuitively obvious in the sense that firms under the RJV can choose the outcome under the R&D non-cooperation whenever it is a better outcome. Note that neither involuntary spillovers nor spillover costs affects firms' decision as to whether to join in an RJV without RJV formation costs..

Definition 1: Define the function $\overline{V^J}(k) = \max\{V^{MIN}(k), V^{MAX}(k)\}$ where, $\overline{V^J}(k) = V^{MAX}(k)$ for $0 < k < k^c$ and $\overline{V^J}(k) = V^{MIN}(k)$ for $k > k^c$.

Lemma 1: As long as there is no RJV formation cost ($F = 0$), for any $k > 0$ the firms always prefer joining in a RJV.

Proof: $\overline{V^J}(k) = \max\{V^{MIN}(k), V^{MAX}(k)\} \geq V^{MIN} > 2V^N$

[20] See Katz (1986), Katsoulacos and Ulph (1998), and Poyago-Theotoky (1999). In these studies, the maximal spillovers are obtained, given the assumption of Cournot competition and homogenous good in the final market.

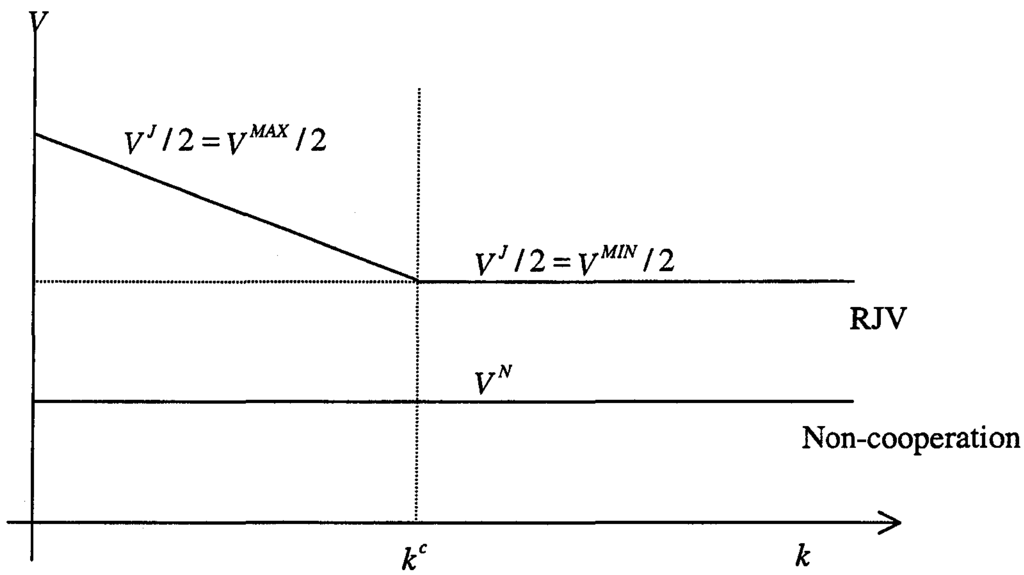

Figure 2.1 Firms' decision of whether to join in an RJV ($F = 0$)

If RJV formation costs exist ($F > 0$), spillover costs as well as RJV formation costs affect firms' decision as to whether they will join in an RJV or not. To be more specific, we consider two critical levels of RJV formation costs, F^{vc1} and F^{vc2}, where:

$$F^{vc1} \equiv \frac{V^{MIN}}{2} - V^N = \frac{18\gamma^2(A-c)^2(2\theta-1)^2}{\{9\gamma-2(1+\theta)(2-\theta)\}^2\{9\gamma-2(1+\theta)^2\}} > 0$$

$$F^{vc2} \equiv \frac{V^{MAX}}{2} - V^N = \frac{\gamma(A-c)^2 D}{\{9\gamma-2(1+\theta)(2-\theta)\}^2\{9\gamma-8\}} - k(1-\theta) > 0, \text{ where } k < k^c$$

$$D \equiv \{9\gamma-2(1+\theta)(2-\theta)\}^2 - \{9\gamma-2(2-\theta)^2\}(9\gamma-8)$$

It is straightforward to show $F^{vc1} < F^{vc2}$ because the joint profit under Case MAX is bigger than under Case MIN ($V^{MAX} > V^{MIN}$) for $k < k^c$. As seen in Lemma 2 (also, see Figure 2), there are three cases to analyze, depending on RJV formation costs. If RJV formation costs are very low, $F < F^{vc1}$, then the firms always prefer joining in an RJV whatever spillover costs are since the RJV, without RJV formation costs, can guarantee at least the gains of F^{vc1} as per firm profit, compared to the R&D non-cooperation. However, the firms do not have an incentive to join in an RJV when RJV formation costs are very high, $F > F^{vc2}$. Spillover costs do not affect firms' decision as to whether to join in an RJV because the maximum gains under the RJV each firm earns without RJV formation costs are F^{vc2} regardless of spillover costs.

Lemma 2: Suppose that there exist RJV formation costs ($F > 0$). Then, a) for $F < F^{vc1}$, firms will always join in an RJV regardless of the magnitude of spillover costs. b) for $F^{vc1} < F < F^{vc2}$, firms will join in an RJV only if $k < k^c$. c) for $F > F^{vc2}$ firms will not join in a RJV whatever spillover costs are.

Proof: a) $\overline{V^J}(k, F=0)/2 - V^N = \max\{V^{MIN}(k, F=0)/2, V^{MIN}(k, F=0)/2\} - V^N \geq F^{vc1}$.

b) $\overline{V^J}(k > k^c, F=0)/2 - V^N = V^{MIN}(F=0)/2 - V^N = F^{vc1}$

$\overline{V^J}(k < k^c, F=0)/2 - V^N = V^{MAX}(k < k^c, F=0)/2 - V^N = F^{vc2} > F^{vc1}$

c) $\overline{V^J}(k, F=0)/2 - V^N = \max\{V^{MIN}(k, F=0)/2, V^{MIN}(k, F=0)/2\} - V^N \leq F^{vc2}$

Meanwhile, for a moderate RJV formation cost ($F^{vc1} < F < F^{vc2}$), firms have to consider spillover costs as a key determinant as to whether they will join in an RJV or not. If spillover costs are sufficiently high ($k > k^c$), then firms will not join in an RJV because the firms under the RJV will choose minimal spillovers, but the profit is smaller with RJV formation costs $F \in (F^{vc1}, F^{vc2})$ than under the R&D non-cooperation. If spillover costs are relatively low ($k < k^c$), however, firms will join in an RJV because they will choose maximal spillovers under the RJV, and it will guarantee the gains of F^{vc2}, compared to R&D non-cooperation. The intuition from Lemma 2 gives an explanation of why a potentially profitable RJV sometimes does not start in a real economy.[21] By our analysis, the RJV will not be formed if RJV formation costs are very high or if RJV formation costs are moderate but spillover costs are sufficiently high.

[21] For an example see Pérez-Castrillo and Sandonís (1996). They explain this fact with moral hazard problem regarding information disclosure between partners.

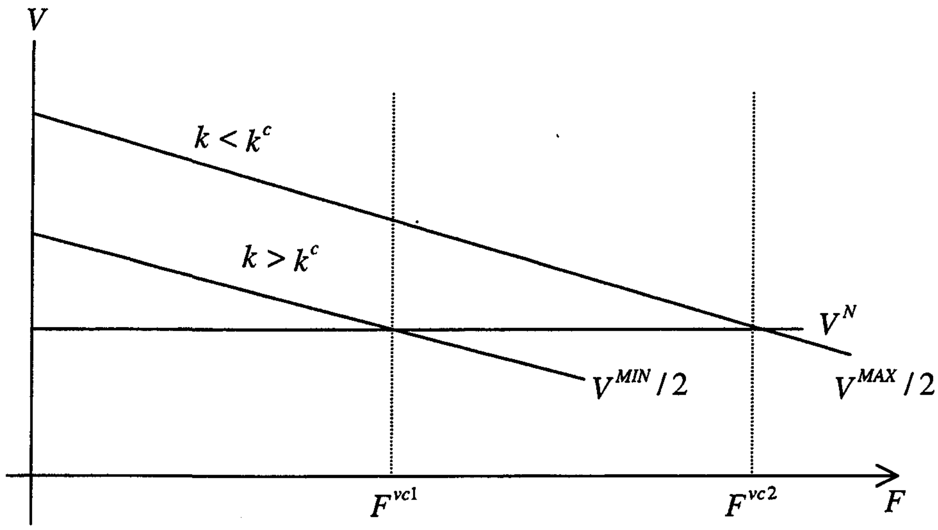

Figure 2.2 Firms' decision of whether to join in an RJV ($F > 0$)

2.4 Welfare implications

In the previous section, we have examined when firms prefer joining in an RJV and when they choose minimal or maximal spillovers. The key determinants are RJV formation and spillover costs while the amount of involuntary spillovers does not affect firm's decision as to whether to join in a RJV. In this section, we compare outcomes between the R&D non-cooperation and the R&D cooperation (RJV) in terms of total welfare, which is the sum of the profits and the consumer surplus (*CS*), and suggest some policy implications.

The firms' incentive to invest in R&D is highest under Case MAX because they can completely internalize externality due to spillovers ($\chi^{MAX} \geq \chi^{MIN}$, and $\chi^{MAX} > \chi^{N}$). The final output increases with R&D investment. Thus, aggregate output is largest while market price is lowest under Case MAX ($P^{MAX} \leq P^{MIN}$, $P^{MAX} < P^{N}$), which implies that the consumer surplus is biggest when the firms under the RJV choose maximal spillovers ($CS^{MAX} \geq CS^{MIN}$, $CS^{MAX} > CS^{N}$). Meanwhile, the degree of involuntary spillovers plays a key role in comparing outcomes between Case MIN and Case N. Note that Case MIN takes place as equilibrium under the RJV if spillover costs are sufficiently high. If the degree of involuntary spillovers is sufficiently high ($\theta > 1/2$), R&D investment is greater under Case MIN than under case N while the opposite is true for sufficiently low involuntary spillovers ($\theta < 1/2$), i.e., $\chi^N >=< \chi^{MIN} \Leftrightarrow \theta <=> 1/2$. Intuitively, for sufficiently high involuntary spillovers the firm under the R&D non-cooperation fears that its R&D investment intensifies cost advantage of the rival firm through spillovers, which decreases incentive of each firm to invest in R&D. However, if the degree of involuntary spillovers is low the effect of R&D investment on cost reduction of the other firm is small. The cost advantage is bigger for the firm that invests in more R&D, which increases the incentive to invest in R&D. On the other hand, the firms under the RJV consider the effect of R&D investment on joint profits. Obviously, we get the opposite result from the R&D non-cooperation since R&D investment of each firm increases (decreases) profits of the other firm for sufficiently high (low) involuntary spillovers. It is straightforward to show that aggregate output and consumer surplus is larger (smaller) under Case MIN than under Case N for sufficiently high (low) involuntary spillovers, i.e., $Q^N >=< Q^{MIN} \Leftrightarrow \theta <=> 1/2$ and $CS^N >=< CS^{MIN} \Leftrightarrow \theta <=> 1/2$.

For the comparison of total welfare between the R&D non-cooperation and the RJV, we have to consider three factors: involuntary spillovers (information leakages), spillover costs, and RJV formation costs. First, suppose that spillover costs are sufficiently high, $k > k^c$. The firms under the RJV choose minimal spillovers (Case MIN). If the degree of involuntary spillovers is sufficiently low, $\theta < 1/2$, total welfare under the RJV is less than under the R&D non-cooperation regardless of RJV formation costs ($W^{MIN} < W^N$). This is because the consumers' loss due to reduced R&D investment under case MIN dominates firms' gains, that is, $CS^{MIN} \leq CS^N$, $|CS^{MIN} - CS^N| > 2F^{vc1} \equiv V^{MIN}(F=0) - 2V^N$. Recall that the firms join in an RJV only if RJV formation costs are relatively low, $F < F^{vc1}$, while they do not for relatively high RJV formation costs, $F > F^{vc1}$. Thus, if RJV formation costs are relatively high ($F > F^{vc1}$), government intervention is unnecessary since the firms do not join in an RJV and total welfare is bigger under the R&D non-cooperation than under the RJV (see Figure 3). However, for relatively low RJV formation costs ($F < F^{vc1}$) government should discourage firms from joining in an RJV since firms' decision of joining in an RJV is not desirable in terms of total welfare. A possible policy may be a tax on RJV.

Lemma 3: Suppose that spillover costs are sufficiently high ($k > k^c$), but involuntary spillovers are sufficiently low ($\theta < 1/2$). Then, the government should discourage firms from joining in an RJV for $F < F^{vc1}$ while it needs not implement any policy for $F > F^{vc1}$.

Proof: It is a straightforward result from Lemma 2 and $W^{MIN} < W^N$ for $\theta < 1/2$

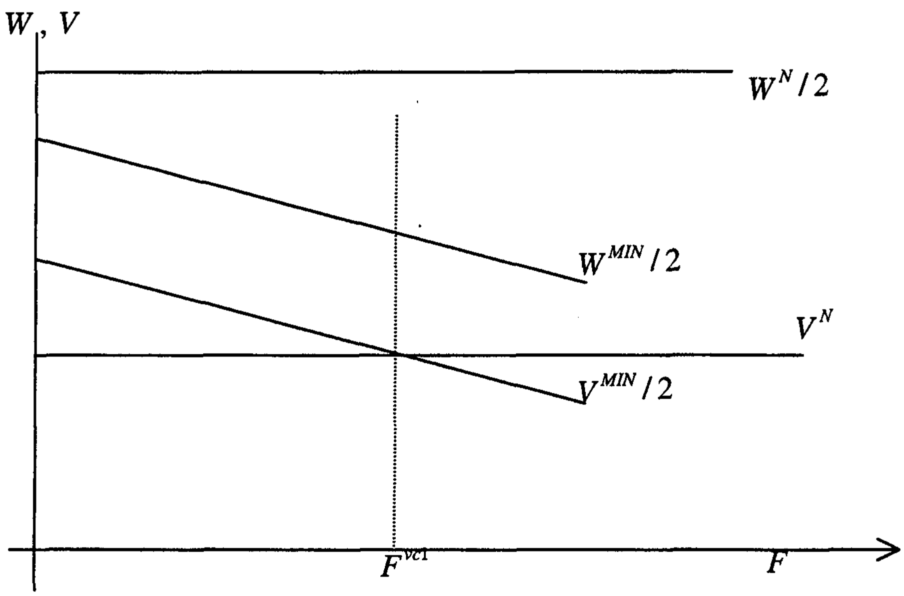

Figure 2.3 Welfare comparison and Policy implication ($k > k^c$, $\theta < 1/2$)

However, if involuntary spillovers are sufficiently large ($\theta > 1/2$), we have different policy implications. The consumers make gains under the RJV since aggregate output (market price) is greater (lower) than under R&D non-cooperation. The profit of the firm is also bigger under the RJV if RJV formation costs are relatively low, $F < F^{vc1}$. Therefore, with RJV formation costs, $F < F^{vc1}$, no government intervention is necessary since private and public interests are consistent in the sense that the firms prefer joining in an RJV while total welfare is bigger under the RJV than under the R&D non-cooperation. Government intervention is unnecessary even when RJV formation costs are very high[22]

[22] $W^{MIN} >=< W^N \Leftrightarrow F <=> F^{wc1}$ where, $F^{vc1} < F^{wc1}$ for $\theta > 1/2$.

($F > F^{wc1}$, where $F^{wc1} \equiv \frac{W^{MIN}(F=0) - W^N}{2} = \frac{72\gamma^2(A-c)^2(1-2\theta)\Phi(\theta,\gamma)}{\{9\gamma - 2(1+\theta)^2\}^2\{9\gamma - 2(1+\theta)(2-\theta)\}^2}$, and $\Phi(\theta,\gamma) \equiv (1+\theta)^3 - 9\gamma(1+\theta) + 6.75\gamma$). But the reason is different from the previous case. Unlike in the previous case, RJV formation is not desirable in terms of both firms' profits and total welfare. Meanwhile, for moderate value of RJV formation costs ($F^{vc1} < F < F^{wc1}$), firms will not join in an RJV but total welfare is higher under the RJV than under the R&D non-cooperation. Therefore, government should encourage firms to join in an RJV. The subsidy on RJV may be a possible policy.

Lemma 4: Suppose both spillover costs and involuntary spillovers are sufficiently high, i.e., $k > k^c$ and $\theta > 1/2$. a) The government does not have to implement any policy for very low or very high RJV formation costs, i.e., $F < F^{vc1}$ or $F > F^{wc1}$. b) The government should encourage firms to join in an RJV for moderate value of RJV formation costs ($F^{vc1} < F < F^{wc1}$).

Proof: $W^{MIN} >=< W^N \Leftrightarrow F <=> F^{wc1}$, where $F^{vc1} < F^{wc1}$ for $\theta > 1/2$. Also, see Lemma 2.

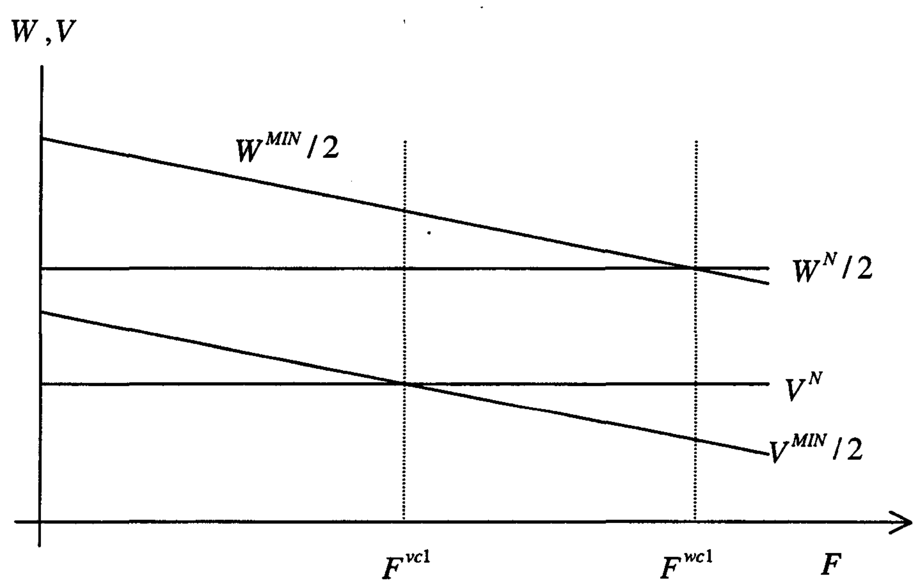

Figure 2.4 Welfare comparison and Policy implication ($k > k^c$, $\theta > 1/2$)

Now, suppose that spillover costs are sufficiently low, $k < k^c$. Then, the firms will completely share their information if they join in an RJV (Case MAX). Without RJV formation costs, total welfare is maximized under case MAX ($CS^{MAX} \geq CS^{MIN}, CS^N$ and $V^{MAX} \geq V^{MIN}, V^N$). With RJV formation costs, total welfare under case MAX is greater than under case MIN, but the comparison of total welfare between case MAX and case N is determined by RJV formation costs. Even if the firms within an RJV share their information completely, RJV formation is not beneficial for very high RJV formation costs ($W^{MAX} < W^N$ if $F > F^{wc2}$, $F^{wc2} \equiv \dfrac{W^{MAX}(F=0) - W^N}{2} = \dfrac{4\gamma(A-c)^2\Omega(\theta,\gamma)}{\{9\gamma - 2(1+\theta)^2\}^2(9\gamma-8)^2} - 2k(1-\theta)$ where, $k < k^c$ and $\Omega(\theta,\gamma) \equiv (9\gamma-4)\{9\gamma - 2(1+\theta)(2-\theta)\}^2 - \{9\gamma - (2-\theta)^2\}(9\gamma-8)^2$. Since the firms will not join in an RJV, government does not have to implement any policy when RJV formation costs are very high ($F > F^{wc2}$). Recall that the firms will not join in an RJV for sufficiently high RJV formation costs ($F > F^{vc2}$ where $F^{vc2} < F^{wc2}$). If RJV formation costs are sufficiently low ($F < F^{vc2}$), the government intervention is also unnecessary because the firms will join in an RJV and total welfare is higher under the RJV than under the R&D non-cooperation. However, if RJV formation costs lie in a median range ($F^{vc2} < F < F^{wc2}$), government should implement a policy to encourage firms to join in a RJV because total welfare is high under the RJV while firms do not prefer joining in a RJV. A possible policy may be subsidy on RJV.

Lemma 5: Suppose spillover costs are sufficiently low, $k < k^c$. Then, a) the government does not have to implement any policy for very low or high RJV formation cost ($F < F^{vc2}$ or $F > F^{wc2}$), b) The government should encourage firms to join in a RJV for a moderate value of RJV formation cost ($F^{vc2} < F < F^{wc2}$).

Proof: It is a straightforward result from Lemma 2 and $W^{MAX} <=> W^N \Leftrightarrow F >=< F^{wc2}$.

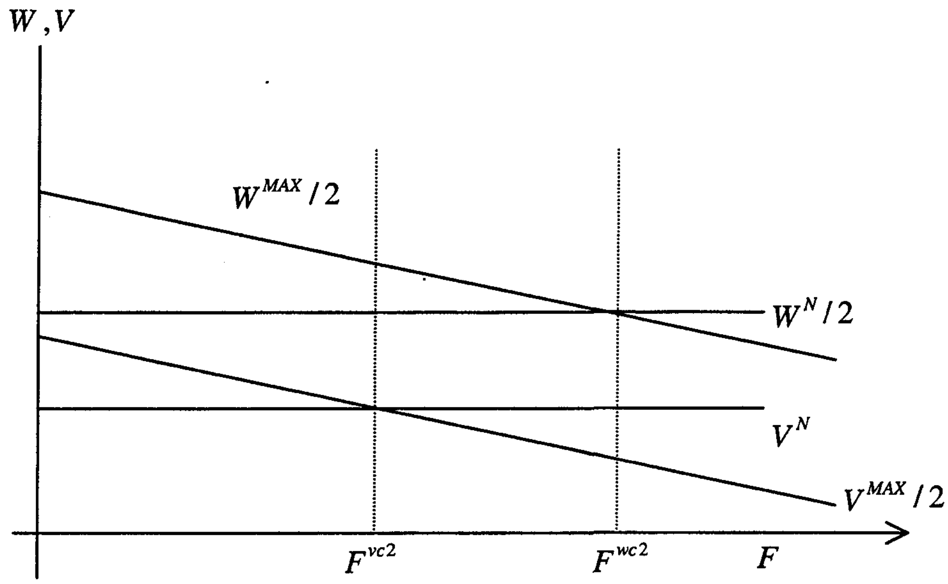

Figure 2.5 Welfare comparison and Policy implication ($k < k^c$)

Table 2.2 Summary of policy implication

$k > k^c$	A. $\theta < 1/2$ $F < F^{vc1}$: Intervention (Discourage (tax) RJV) $F > F^{vc1}$: No intervention (Private and public interests are consistent) B. $\theta > 1/2$ $F < F^{vc1}$: No intervention (Private and public interests are consistent) $F^{vc1} < F < F^{wc1}$: Intervention (Encourage (subsidy) RJV) $F > F^{wc1}$: No intervention (Private and public interests are consistent)
$k < k^c$	$F < F^{vc2}$: No intervention (Private and public interests are consistent) $F^{vc2} < F < F^{wc2}$: Intervention (Encourage (subsidy) RJV) $F > F^{wc2}$: No intervention (Private and public interests are consistent)

2.6 Conclusion

This chapter considers the problem of R&D competition in the presence of spillovers. Unlike most previous studies where spillovers are treated as exogenous, we allow spillovers to be determined endogenously. The other important feature in our model is to introduce costly RJV formation, which is more reasonable in a real economy as suggested by Vilasuso and Frascatore. Two main questions we have asked in this chapter are whether firms under the RJV (or R&D cooperation) will choose to share their information completely, and whether private interests are consistent with public interests in terms of total welfare.

Regarding the first question, we showed that the firms under the RJV would achieve complete information sharing only if spillover costs are sufficiently low. Meanwhile firms under the RJV do not share any information if spillover costs are very high. This result is novel in the sense that it was never found in previous studies where a homogenous good and Cournot competition in the final market are assumed. Unlike previous studies where they suggest that private interests on RJV are consistent with public interests, we also found that private interests with an RJV are not consistent with public interests for a wide range of parameter values. Thus, we suggest the potential need for active government intervention on RJV formation. As seen in previous sections, RJV formation costs, spillover costs, and involuntary spillovers are key determinants of which policy government should consider when it decides whether to intervene or not.

The main policy implications are as follows. First, if spillover costs and the degree of involuntary spillover are sufficiently high and low, respectively, then the government should discourage firms from joining in an RJV for relatively low RJV formation costs while no government intervention is necessary for relatively high RJV formation costs. Second, if both spillover costs and the degree of involuntary spillover are sufficiently high, then the government does not have to implement any policy for very low or high RJV formation costs, while government should encourage firms to join in an RJV for a moderate level of RJV formation costs. Finally, if spillover costs are sufficiently low, the same results as in the second case are obtained, but it is shown that the critical value of RJV formation costs is different.

There are some possible extensions of this paper. As mentioned earlier, the assumption of 'joint profit maximization' under the RJV may be inappropriate, especially when the two firms are rivals in the final market. Thus, it is worthwhile to investigate the relevancy of the 'joint profit maximization' assumption under an RJV. A second possible extension is to consider a case in which firms face Bertrand competition with differentiated products in a final market. This may help examine the robustness of the results obtained in this paper. A third extension is to introduce initially asymmetric firms. Then, probably we may have to find asymmetric outcomes as equilibrium, thus we may obtain a more practical policy implication. The last extension is to introduce a research design step and consider different research outcomes. This is obviously more realistic and it may help understand the role of information sharing.

CHAPTER 3. WELFARE EFFECTS OF INTELLECTUAL PROPERTY RIGHTS UNDER ASYMMETRIC SPILLOVERS

3.1 Introduction

The Uruguay round established a global agreement on intellectual property, which is called TRIPS (Traded-related aspects of intellectual property rights). Under this agreement, most developing countries should introduce the international minimum standards of protection by 2006. The recent debate in the WTO (World Trade Organization) meeting has been whether it is desirable to extend IPR protection to the least developed countries. About this issue, the declaration in the Doha round extends the deadline for the least developed countries to introduce patent protection on pharmaceuticals until 2016. It seems reasonable in the sense that the least developed countries do not have the capacity to absorb new knowledge from the innovations while they desperately need the products developed by northern firms.

This chapter examines the welfare effects of intellectual property rights (IPR) protection in terms of north-south trade. We ask which southern countries, if any, should provide more IPR protection, assuming that the differentiated IPR protection among southern countries can be made through a WTO agreement. Yang (1998) showed, using a partial equilibrium model, that both the North and the South would be better off if some southern countries impose more IPR protection while the others impose less. However, he does not identify which southern countries should provide more IPR protection for the northern technology.[1]

Chin and Grossman (1988), using a duopoly model with one firm from the South and the other from the North, compare the welfare effects of IPR protection between two regimes: 'full IPR protection' and 'no IPR protection'. They show that the economic interests of the North and the South are generally in conflict in the sense that 'no IPR protection' benefits the South while it hurts the North. Žigić (1998) extends Chin and Grossman's model

[1] This is because he assumes that all southern countries are identical.

by introducing spillovers, which is interpreted as the inverse index of IPR protection. The southern firm can take advantage of the benefits from the innovations of northern firm through spillovers. By considering only one southern country and a common spillover parameter, however, he ignores the fact that the southern countries may face different spillovers. In Levin et al. (1987) and Cohen and Levinthal (1989), firms may be different in their abilities to absorb or assimilate intra-industry spillovers.[2]

We extend Žigić by introducing different spillovers among southern countries to examine welfare effects of IPR protection. Only the northern country innovates, and n-1 southern countries have different capacities to absorb knowledge spillovers from the northern innovations.[3] We assume, as in Žigić, the abilities to absorb spillovers in any southern country decrease (increase) when IPR protection is tightened (relaxed). A two-stage game is considered. In the first stage, the northern firm invests in R&D to create the new process. The outcome of innovations reduces the unit production cost of northern firm. The technology developed by the northern firm provides benefits to the southern firms through spillovers. The degree of spillovers is different across southern firms depending on the ability to realize knowledge spillovers. In the second stage, all firms engage in Cournot competition.

The spillover share, which is defined as the spillovers in any country divided by the sum of spillovers for all countries, plays a crucial role in determining the welfare effects of IPR protection. Some findings obtained in this chapter are as follows. The spillover expansion from relaxed IPR protection in any southern country may or may not reduce the unit production cost in that country, depending on the spillover share. The profit of the firm always increases whenever its unit production cost decreases with spillovers. There is a possibility that the profit effect of spillovers is also positive even when it raises unit production costs. This happens when the R&D efficiency of the northern firm is sufficiently low or if the spillover share is not too big. Meanwhile, the effects of relaxed IPR protection in any southern country on aggregate output and consumer surplus are negative as long as the

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[2] Cohen and Levinthal (1989) calls this ability 'absorptive capacity'.

[3] In terms of the North, the issue of IPR protection may be 'imitation' of southern countries rather than spillovers. Usually, 'imitation' and 'spillovers' are interpreted differently in the sense that 'imitation' is costly while 'spillovers' are costless. By different capacity to absorb spillovers, however, we are implicitly considering costly spillovers. Thus, the terms 'imitation' and 'spillovers' are interchangeable in this chapter even though we prefer 'spillovers', following Žigić.

sum of spillovers is relatively large. However, its effects become positive if the sum of spillovers is relatively small and the R&D efficiency is very low.

The welfare effects of spillovers depend on both the consumption share and the spillover share. The southern countries can be classified into three groups in terms of welfare effects of spillovers. Two critical values of the consumption share, which are quadratic functions of the spillover share, play a key role in classifying southern countries into three groups. The countries in the first group are better off from relaxed IPR protection both in their own countries and in the other countries. The countries in the second group are better off from spillovers in their country, but worse off from spillovers in the other group. The third group suffers from welfare loss when IPR protection is relaxed in any southern country. The northern country is worse off for a wider range of R&D efficiency and the sum of spillovers, when the degree of IPR protection decreases in any southern country.

This chapter is organized as follows. Section 2 provides a brief literature review on IPR protection in terms of North-South trade. Section 3 sets up the model and identifies the equilibrium while section 4 provides some comparative statics. Section 5 investigates welfare effects of spillovers and suggests some implications. The last section provides conclusions.

3.2 Literature Review

The literature dealing with the problem of IPR (Intellectual Property Right) protection in the context of North-South trade has not reached any consensus until now. Chin and Grossman (1988) seem to be the first to contribute to this issue. Using a duopoly model with one firm from the South and the other from the North, they compare the welfare effects of IPR protection between two regimes: full IPR protection and no IPR protection. They show that the economic interests of the North and the South are generally in conflict in the sense that the South benefits from 'no IPR protection' while it hurts the North. Diwan and Rodrik (1991) argue northern and southern countries generally have different preferences for technology. They model the 'appropriate technology' for southern countries, and suggest that southern countries can benefit from IPR protection. Deardorff (1992) argues that, when IPR protection increases, the North is always benefited while the South is hurt, and emphasizes that the effect on world welfare will be negative if IPR protection is extended to all southern countries. Helpman (1993) suggests that tightening IPR protection hurts both North and South in the presence of slow imitation while it benefits only the North when the imitation rate is high. He also points out that higher protection of IPR by the South could lead to slow innovation of northern firms, partly because of the lack of competition.

Žigić (1998) extends Chin and Grossman's model by introducing technological spillovers to examine the role of IPR protection when only the northern firm conducts innovative activity. The degree of spillovers is interpreted as an indicator of the inverse strength of IPR protection. He shows that the South may benefit from tightening IPR protection through the spillover effect of the increased northern firm's R&D investment. Given that innovation should be protected for sufficient innovations of the northern firm, the conflict may be enlarged across southern countries in the sense that each southern country has an incentive to wait for other southern countries to provide more protection. Yang (1998) suggests that the cooperation for IPR protection among some southern countries will make mutual gains to both North and South. The remaining question is which southern countries should provide more IPR protection.

3.3 The Model and Equilibrium

3.3.1 The Model

There exist n countries in the world market: one northern country (labeled by 1) and n-1 southern countries (labeled by 2,3,….,n). We assume that there exist at least four southern countries.[4] Thus, $n \geq 5$. Each country has only one firm. All innovations take place in the northern country, which conducts R&D. By the spillover effect, n-1 southern countries can partly appropriate the knowledge generated by the northern country, depending on their knowledge absorptive abilities and the IPR protection level. Both North and South have access to an old technology to produce a good demanded in the world market.

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[4] We may think that southern countries can be classified into two groups, and each group consists of at least two countries. This may help identify which countries, if any, should cooperate to provide more IPR protections. However, the results obtained in this chapter qualitatively hold for $n \geq 3$.

The northern firm has the following unit production cost function, which is originally used by Chin and Grossman (1988): $C_1 = \alpha - (\gamma\chi)^{1/2}$, where α describes pre-innovation cost, and γ is a parameter denoting the R&D efficiency. The term, $(\gamma\chi)^{1/2}$, represents the R&D production function, which exhibits diminishing returns to scale with respect to R&D investment, χ .[5] The i^{th} southern firm's unit cost function is $C_i = \alpha - \beta_i(\gamma\chi)^{1/2}$, $i = 2,3,\ldots, n$ where $\beta_i \in (0,1)$ denotes the index of spillovers or the strength of inverse IPR protection as in Žigić (1998). It may be reasonable to think that the spillover parameter consists of two terms: IPR protection level and country-specific characteristic. The country-specific characteristic may include the country's ability to absorb R&D knowledge,[6] or it may reflect imitation ability. Thus, even if southern countries face common IPR protection level, the value of the spillover parameter may be different across southern countries, depending on the ability to absorb R&D knowledge (or imitation ability). We assume that the southern country 2 has the highest ability to realize R&D knowledge while southern country n has the least ability: [7] $\beta_2 > \beta_3 > \ldots\ldots > \beta_n$, thus $C_2 < C_3 < \ldots\ldots < C_n$. We assume away two extreme cases, $\beta_i \equiv 0$ and $\beta_i \equiv 1$, which may reflect 'perfect protection' and 'no protection' of intellectual property right, respectively.[8]

Note that $\beta_1 \equiv 1$ in our set-up. It is straightforward to show that the sum of spillovers is less than the number of countries in the market, i.e., $\sum_{j=1}^{n} \beta_j < n$. The consumers are identical, and country i's consumers consume $\theta_i \in [0,1]$ proportion of total demand,

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[5] For more detail, see D'Aspremont and Jacquemin (1988) and Kamien et al. (1992).

[6] Following Cohen and Levinthal (1989), we may call this ability 'absorptive capacity'.

[7] It may be possible for each southern country to increase the amount of spillovers by making some efforts to increase 'absorptive capacity' as well as from relaxed IPR protection. Thus, introducing endogenous spillovers may be an interesting issue to tackle, but beyond this chapter. We assume throughout this chapter that the spillover expansion in any southern country takes place only when IPR protection is relaxed.

[8] Even if IPR protection is perfect ($\rho_i = 0$), the value of spillover parameter may not be zero, i.e., $\beta_i > 0$, as long as we assume that the spillover parameter takes a strongly separate form, i.e., $\beta_i = \rho_i + \omega_i$, where ρ_i and ω_i denote inverse IPR protection level and country's ability to absorb knowledge, respectively. One thing to note is the results obtained in this chapter do not hold if the value of spillover parameter takes zero, i.e., $\beta_i \equiv 0$.

which is given as a linear inverse demand function: $P = A - Q$, $Q = \sum q_i$. Here, A is sufficiently large to exceed α (A > α) so that it guarantees an interior equilibrium. q_i represents the final production of each country.

Assumption 1: (1) There exists at least four southern countries in the market, $n-1 \geq 4$ or $n \geq 5$. (2) $\beta_1 > \beta_2 > \beta_3 > .... > \beta_n$, where $\beta_1 \equiv 1$, $\beta_i \in (0,1)$ $i = 2,3,....,n$.

Lemma 1: Let $s_i \equiv \beta_i \Big/ \sum_{j=1}^{n} \beta_j$ be the spillover share of country *i*. Then, by Assumption 1, $s_1 > 1/n$, $s_n < 1/n$, and $s_i < 1/2$ where, $i = 2,3,....,n$.

Proof) $\beta_1 \equiv 1$, $\sum_{j=1}^{n} \beta_j < n$, $\sum_{j=1}^{n} \beta_j > n\beta_n$, thus $s_1 > 1/n$, $s_n < 1/n$.

For $i = 2,3,....,n$, $s_i \equiv \beta_i \Big/ \sum_{j=1}^{n} \beta_j < \beta_i / (1+\beta_i) < \beta_i / 2\beta_i \equiv 1/2$.

3.3.2 Equilibrium

The game among *n* countries consists of two stages, and the nature of the equilibrium is the subgame perfect Nash equilibrium. In the first stage, the northern country chooses R&D investment, χ. In the second stage, given the northern firm's R&D investment, the *n* firms engage in Cournot-Nash competition. To find the subgame perfect equilibrium, we first solve for the Nash equilibrium in the second stage and then work backwards solving for the first stage R&D level. In the second stage, each firm maximizes its profit: $\pi_i = P(Q)q_i - c_i q_i$ for all $i = 1,......,n$. The first order condition of any country *i* is $a - Q - q_i - c_i = 0$ for all $i = 1,......,n$. Solving the first order condition for *n* firm simultaneously, we get the following Cournot outcome as function of R&D investment:

(1) $$q_i = \frac{A - nc_i + \sum_{j \neq i}^{n} c_j}{n+1}, \quad p = \frac{A + \sum_{j=1}^{n} c_j}{n+1}, \quad Q = \frac{nA - \sum_{j=1}^{n} c_j}{n+1}$$

In the first stage, given the second stage outcome, the northern firm chooses χ to maximize its profit (including R&D cost):

$$(2)\ V_1 = \frac{(A - nc_1 + \sum_{j=2}^{n} c_j)^2}{(n+1)^2} - \chi = \frac{[A - n\{\alpha - (\gamma\chi)^{1/2}\} + \sum_{j=2}^{n}\{\alpha - \beta_j(\gamma\chi)^{1/2}\}]^2}{(n+1)^2} - \chi$$

The first order condition is:

$$(3)\ \frac{\{(A-\alpha)(n+1-\sum_{j=1}^{n}\beta_j)\gamma^{1/2}\chi^{-1/2} + (n+1-\sum_{j=1}^{n}\beta_j)^2\gamma\}}{(n+1)^2} - 1 = 0$$

The second order condition is $\dfrac{-\{(A-\alpha)(n+1-\sum_{j=1}^{n}\beta_j)\gamma^{1/2}\chi^{-3/2}\}}{2(n+1)^2} < 0$ for all $\chi > 0$.

From the first order condition, we obtain the equilibrium R&D investment.

$$(4)\ \chi^* = \frac{(A-\alpha)^2\gamma\Delta^2}{\{(n+1)^2 - \gamma\Delta^2\}^2}, \text{ where}^{9}\ \Delta \equiv n+1-\sum_{j=1}^{n}\beta_j > 0$$

As seen in equation (4), the equilibrium R&D investment becomes infinite at a level of large R&D efficiency. To avoid this situation, we assume $\gamma < \bar{\gamma} \equiv \dfrac{(n+1)^2}{\Delta^2}$. Replacing the final production with the equilibrium R&D investment, χ^*, yields: for $i = 2,3,\ldots, n$ $q_i = \dfrac{(A-\alpha)\{(n+1) - \gamma(1-\beta_i)\Delta\}}{(n+1)^2 - \gamma\Delta^2}$ and for the northern firm, $q_1 = \dfrac{(A-\alpha)(n+1)}{(n+1)^2 - \gamma\Delta^2}$. For all countries to produce positive amounts, $\gamma < \gamma^n \equiv \dfrac{(n+1)}{(1-\beta_n)\Delta}$ is required, which is equivalent to the condition for southern country n to produce. This condition guarantees that all countries produce positive amounts because the output of the southern country n is smallest.

[9] Henceforth, this expression, $\Delta \equiv n+1-\sum_{j=1}^{n}\beta_j > 0$, is assumed to hold.

We may need to restrict the upper bound of R&D efficiency more since γ^n depends on the spillover parameter, β_n. Since γ^n has the smallest value when β_n is closest to zero, the appropriate condition for n-firm oligopoly existence in the world market will be:

(5) $\gamma < \overline{\gamma}^n \equiv (n+1)/\Delta$ where, $\overline{\gamma}^n < \overline{\gamma}, \gamma^n$.

For the later use, we define market share for each country with $z_k \equiv q_k/Q$.

Definition 1: Let $z_k \equiv q_k/Q$ be market share for any country *k*. Then, $z_k \equiv \lambda + \eta s_k$, where

$$\lambda \equiv \frac{(n+1) - \gamma\Delta}{n(n+1) - \gamma\Delta(\Delta-1)} > 0\,,\ \eta \equiv \frac{\gamma\Delta\sum_{j=1}^{n}\beta_j}{n(n+1) - \gamma\Delta(\Delta-1)} > 0$$

It may be desirable to compare the condition for n-firm oligopoly in our model with that for the duopoly to exist both in Chin and Grossman (1988) and Žigić (1998). The condition for the duopoly to exist in Chin and Grossman and Žigić are $\gamma < 3/2$ and $\gamma < 3/\{(1-\beta)(2-\beta)\}$, respectively. Two countries, the North and the South, are modeled in both papers. Chin and Grossman consider 'perfect protection' of intellectual property right while Žigić assumes that southern country can take advantage of the benefits from northern firm's innovation through spillovers. The condition in Chin and Grossman can be recovered in our set-up by setting n=2 and $\beta_2 = 0$ while Žigić's condition is obtained by putting n=2 and $\beta_2 = \beta$.

Both Chin and Grossman and Žigić consider two more types of equilibria: monopoly and strategic predation. They show that the northern firm will enjoy the pure monopoly position for a sufficiently high value of R&D efficiency parameter (γ) while it will act strategically to induce southern firm's exit (strategic predation) for an intermediate value of R&D efficiency. These two types of equilibria can exist when there is more than one southern country in the world. The monopoly condition[10] in our set-up is $\gamma > \frac{2}{1-\beta_2}$. The same condition for the monopoly is obtained in Žigić where only one southern country is assumed. Note $\gamma > 2$ is the condition for the monopoly in Chin and Grossman where they consider perfect protection of intellectual property right ($\beta = 0$). The condition for strategic predation is $3/2 < \gamma < 2$ and $3/\{(1-\beta)(2-\beta)\} < \gamma < 2/(1-\beta)$ in Chin and Grossman and Žigić, respectively. In our set-up, $(n+1)\Big/\{(1-\beta_2)(n+1-\sum_{j=1}^{n}\beta_j)\} < \gamma < 2/(1-\beta_2)$ is the condition for strategic predation, which is exactly the same condition as in Žigić if we assume that there exists only one southern country in the market.[11] Even though the outcome comparison among these equilibria is an interesting issue, we do not consider these two equilibria since we are interested in investigating the own and cross welfare effects of spillovers in the southern country.

3.4 Comparative statics

The spillover expansion of southern countries (from relaxed IPR protection) lowers northern firm's R&D investment since it reduces the northern firm's incentive to invest in R&D, that is, $\frac{d\chi^*}{d\beta_k} = \frac{-2\gamma(A-\alpha)^2\Delta\{(n+1)^2+\gamma\Delta^2\}}{\{(n+1)^2-\gamma\Delta^2\}^3} < 0$. Lemma 2 is a straightforward result and it is useful for the later analysis of welfare effects. The spillover elasticity of R&D investment ($\varepsilon_{\chi k}$) is bigger for southern countries with higher spillover share (s_k), which implies that the northern firm reacts more sensitively to the spillover expansion in southern countries with higher spillover share.

[10] This happens when 'drastic innovation' takes place, that is, for i = 2,......, n, $p^m < C_i(\chi^m)$ where m denotes monopoly outcome. Substituting price and R&D with monopoly outcome yields the condition.
[11] The equilibrium R&D investment for strategic predation can be obtained by setting $q_i = 0$ for i = 2,......, n.

Definition 2: Let $\varepsilon_{xk} \equiv -(\beta_k/\chi)(\partial\chi/\partial\beta_k)$ be the spillover (β_k) elasticity of R&D investment,

Then, for $k = 2,3,\ldots\ldots,n$, $\varepsilon_{\chi k} = \dfrac{2s_k \sum_{j=1}^{n}\beta_j\{(n+1)^2 + \gamma\Delta^2\}}{\Delta\{(n+1)^2 - \gamma\Delta^2\}} > 0$

Lemma 2: a) Suppose $\sum_{j=1}^{n}\beta_j > (n+1)/2$. Then, $\varepsilon_{xk} > 2s_k$. b) Suppose $\sum_{j=1}^{n}\beta_j < (n+1)/2$.

Then $\varepsilon_{xk} >=< 2s_k \Leftrightarrow \gamma >=< \gamma^{c1}$, where $\gamma^{c1} \equiv (\Delta - \sum_{j=1}^{n}\beta_j)(n+1)/\Delta^2 < 1$

Proof) It is a straightforward result from the expression of spillover elasticity in Definition 2.

The spillover expansion of any southern country k raises the equilibrium unit production cost of other countries including the northern country because it reduces the northern firm's incentive to invest in R&D ($dC_i/d\beta_k > 0$). Whether it decreases its own unit production cost depends on its spillover share (s_k). If the spillover share in any southern country k is relatively high ($s_k > s^{c1}$), the spillover expansion through relaxed IPR protection raises its unit production cost. The northern firm's reaction to the spillover expansion is more sensitive when spillovers increase in the southern country with higher spillover share. Thus, the direct effect of spillover on unit cost in the southern country with relatively high spillover share is dominated by the indirect effect of the decreased R&D investment. The critical value, s^{c1}, is smaller (bigger) than 1/2 for $\gamma > \gamma^{c2}$ ($\gamma < \gamma^{c2}$), where[12] $\gamma^{c2} \equiv \dfrac{(n+1)^2(2\Delta - \sum_{j=1}^{n}\beta_j)}{\Delta^2(2\Delta + \sum_{j=1}^{n}\beta_j)}$. Note, by Assumption 1, the spillover share in any southern country should be less than $1/2$. Therefore, the spillover expansion in any southern country always decreases its unit production costs if R&D efficiency is sufficiently low ($\gamma < \gamma^{c2}$). Also, the critical value, s^{c1},

[12] $\gamma^{c2} < 0 \Rightarrow s^{c1} < 1/2$ for $(n >)\sum_{j=1}^{n}\beta_j > 2(n+1)/3$.

may be smaller or bigger than $1/(n+1)$, depending on the R&D efficiency. If the R&D efficiency is relatively low ($\gamma < \gamma^{c3}$, where[13] $\gamma^{c3} \equiv \dfrac{(n+1)^2\{(n+1)\Delta - \sum_{j=1}^{n}\beta_j\}}{\Delta^2\{(n+1)\Delta + \sum_{j=1}^{n}\beta_j\}}$), s^{c1} is bigger than $1/(n+1)$ while it is smaller than $1/(n+1)$ for relatively high R&D efficiency ($\gamma > \gamma^{c3}$). This implies that the range of southern countries, in which cost reduction occurs from spillover expansion, widens if the R&D efficiency is relatively low. This is intuitively obvious because the direct effect of spillovers on unit production costs will dominate the indirect effect of the decreased R&D investment of northern firm if R&D efficiency is sufficiently low.

Lemma 3: For $i = 1,2,....,n$, $k = 2,....,n$, and $k \neq i$, (a) $dc_i/d\beta_k > 0$

(b) $dc_k/d\beta_k >=< 0 \Leftrightarrow s_k >=< s^{c1}$, where $s^{c1} \equiv \dfrac{\Delta\{(n+1)^2 - \gamma\Delta^2\}}{\sum_{j=1}^{n}\beta_j\{(n+1)^2 + \gamma\Delta^2\}}$

Proof: (a) $\dfrac{dc_i}{d\beta_k} = \dfrac{\chi^{1/2}}{2}\dfrac{\beta_i}{\beta_k}(-\dfrac{\beta_k}{\chi}\dfrac{\partial\chi}{\partial\beta_k}) = \dfrac{\chi^{1/2}}{2}\dfrac{\beta_i}{\beta_k}\varepsilon_{\chi k} > 0$ since $\varepsilon_{\chi k} > 0$.

(b) $\dfrac{dc_k}{d\beta_k} = -\dfrac{(\gamma\chi)^{1/2}}{2}(2 + \dfrac{\beta_k}{\chi}\dfrac{\partial\chi}{\partial\beta_k}) = -\dfrac{(\gamma\chi)^{1/2}}{2}(2 - \varepsilon_{\chi k}) >=< 0 \Leftrightarrow \varepsilon_{\chi k} >=< 2$

Replacing $\varepsilon_{\chi k}$ with the expression in Definition 2 yields $dc_k/d\beta_k >=< 0 \Leftrightarrow s_k >=< s^{c1}$.

The final output in any southern country increases whenever the spillover expansion yields the reduction of its unit production cost ($dc_k/d\beta_k < 0 \Rightarrow dq_k/d\beta_k > 0$). As seen in Equation (6), the own effect of spillovers on output can be determined by two effects: the own and the cross effect on unit production costs. Since the cross effect of spillover on unit

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[13] $\gamma^{c3} > \bar{\gamma}^{n} \Rightarrow s^{c1} > 1/(n+1)$ for $(n >)\sum_{j=1}^{n}\beta_j > (n^2-1)/n$.

production costs is always positive ($dC_j/d\beta_k > 0$), it is obvious that the own effect of spillover on output is positive as long as its own effect on unit production cost is negative. Recall that the cost reduction by own spillover expansion occurs only for the southern countries with relatively low spillover share ($s_k < s^{c1}$).

(6) $\dfrac{dq_k}{d\beta_k} = \dfrac{-n}{n+1}\dfrac{dC_k}{d\beta_k} + \dfrac{1}{n+1}\sum_{j\neq k}\dfrac{dC_j}{d\beta_k}$, $k = 2,\ldots,n$, $j = 1,2,\ldots,n$.

Interestingly, there is a case where the final output of the firm increases even when its unit costs increase with spillover expansion, that is, $dC_k/d\beta_k > 0$ and $dq_k/d\beta_k > 0$. This happens if the cross effect of spillover on unit production costs dominates its own effect, i.e., $\left|n\, dC_k/d\beta_k\right| < \left|\sum_{j\neq k} dC_j \big/ d\beta_k\right|$. The size of own spillover effect on unit production cost is larger for southern countries with higher spillover share. This is due to the fact that the northern firm reacts more sensitively to the spillover expansion in the southern country with higher spillover share ($d\varepsilon_{\gamma k}/ds_k > 0$). Thus, there exists a critical value, $s^{c2} (> s^{c1})$, which determines whether the output increases with spillovers, i.e., $dq_k/d\beta_k >=< 0 \Leftrightarrow s_k <=> s^{c2}$. The firms in southern countries with the spillover share $s_k \in (s^{c2}, 1/2)$ suffer from the higher unit cost and the production reduction ($dC_k/d\beta_k > 0$ and $dq_k/d\beta_k < 0$) while southern countries with the spillover share $s_k \in (s^{c1}, s^{c2})$ experience $dC_k/d\beta_k > 0$ and $dq_k/d\beta_k > 0$.

The critical value of the spillover share, s^{c2}, also depends on the level of R&D efficiency. s^{c2} is greater than both $1/(n+1)$ and s^{c1} for the range of R&D efficiency we consider in this chapter, i.e., $0 < \gamma < \overline{\gamma}^n$. Meanwhile, if R&D efficiency is sufficiently low ($\gamma < \gamma^{c4}$, where[14] $\gamma^{c4} \equiv \dfrac{(n+1)^2\{2n(n+1) - (3n-1)\sum_{j=1}^{n}\beta_j\}}{\Delta^2\{2n(n+1) - (n+1)\sum_{j=1}^{n}\beta_j\}}$), the critical value, s^{c2}, is greater than 1/2, i.e., $s^{c2} > 1/2$. Therefore, the spillover expansion in any southern country always

[14] $\gamma^{c4} < 0 \Rightarrow s^{c2} < 1/2$ for $(n >)\sum_{j=1}^{n}\beta_j > 2n(n+1)/(3n-1)$

yields the increased production of its firm, regardless of the change in unit production costs, if the R&D efficiency is sufficiently low ($\gamma < \gamma^{c4}$) (see Figure 1).

The spillover expansion in any southern country k always raises unit production costs of the other southern countries ($dC_i/d\beta_k > 0$). Nevertheless, the final output in those countries may increase, depending on the size of spillover effects on unit production costs. Equation (7) analyzes the cross spillover effect on output ($dq_i/d\beta_k$):

$$(7)\ \frac{dq_i}{d\beta_k} = \frac{-n}{n+1}\frac{dC_i}{d\beta_k} + \frac{1}{n+1}\sum_{j\neq i,k}\frac{dC_j}{d\beta_k} + \frac{1}{n+1}\frac{dC_k}{d\beta_k},\ i = 1,2,\ldots.,n,\ k = 2,\ldots.,n,\ i \neq k.$$

The first term on the right hand side has a negative sign while the sign of the second term is positive. The sign of the third term is negative (positive) for southern countries with the spillover share, $s_k < s^{c1}$ ($s_k > s^{c1}$). Thus, we cannot determine the sign of $dq_i/d\beta_k$ without further analysis. Replacing each term with the results in Lemma 3 yields an interesting result (see Lemma 4). The important factor to determine the sign of $dq_i/d\beta_k$ is the spillover share of southern country i (s_i). Technically, we can get the spillover share, s^{c0}, which is a critical value to determine whether changes in spillovers in any given southern country increase or decrease outputs in the other countries. Country i's output increases with spillover expansion in any southern country k only if its own spillover share is sufficiently low ($s_i < s^{c0}$). The critical value s^{c0} is always smaller than $1/(n+1)$ and s^{c1} as well as s^{c2} for $0 < \gamma < \bar{\gamma}^n$. Obviously, the output of the northern firm, whose spillover share is greater than $1/n$, decreases when the degree of IPR protection is lowered in any southern country. One thing to note is that s^{c0} becomes negative if $\sum_{j=1}^{n}\beta_j < (n+1)/2$ and $\gamma < \gamma^{c1}(<1)$. If this occurs, then country i's output always decreases with spillover expansion in any southern country k.

Lemma 4: a) for $k = 2,\ldots.,n$, $dq_k/d\beta_k >=< 0 \Leftrightarrow s_k <=> s^{c2}$

$$\text{where, } s^{c2} \equiv \frac{(n\Delta + \sum_{j=1}^{n}\beta_j)(n+1)^2 - \gamma\Delta^2(n\Delta - \sum_{j=1}^{n}\beta_j)}{\sum_{j=1}^{n}\beta_j(n+1)\{(n+1)^2 + \gamma\Delta^2\}}$$

b) for $i = 1,2,\dots,n$, $k = 2,\dots,n$, and $i \neq k$, $dq_i/d\beta_k >=< 0 \Leftrightarrow s_i <=> s^{c0}$

where, $s^{c0} \equiv \dfrac{(\sum_{j=1}^{n}\beta_j - \Delta)(n+1)^2 + \gamma\Delta^2(n+1)}{\sum_{j=1}^{n}\beta_j (n+1)\{(n+1)^2 + \gamma\Delta^2\}}$

c) $dQ/d\beta_k < 0$ if $\sum_{j=1}^{n}\beta_j > (n+1)/2$. $dQ/d\beta_k <=> 0 \Leftrightarrow \gamma >=< \gamma^{c1}$ if $\sum_{j=1}^{n}\beta_j < (n+1)/2$

Proof) a) $\dfrac{dq_k}{d\beta_k} = \dfrac{n(\gamma\chi)^{1/2}}{n+1} + \dfrac{\gamma^{1/2}\chi^{-1/2}}{2(n+1)}\dfrac{\partial\chi}{\partial\beta_k}\{(n+1)\beta_k - \sum_{j=1}^{n}\beta_j\}$

$= \dfrac{(\gamma\chi)^{1/2}}{2(n+1)\beta_k}\sum_{j=1}^{n}\beta_j\{2n s_k + \dfrac{\beta_k}{\chi}\dfrac{\partial\chi}{\partial\beta_k}\{(n+1)s_k - 1\} = \dfrac{(\gamma\chi)^{1/2}}{2(n+1)s_k}[2n s_k - \{(n+1)s_k - 1\}\varepsilon_{\chi k}]$

Since $\varepsilon_{xk} > 0$, $dq_k/d\beta_k > 0$ if $s_k < 1/(n+1)$

However, if $s_k > 1/(n+1)$, $dq_k/d\beta_k >=< 0 \Leftrightarrow \varepsilon_{\chi k} <=> 2n s_k/\{(n+1)s_k - 1\}$

Replacing ε_{xk} with the expression in Definition 2 yields $dq_k/d\beta_k >=< 0 \Leftrightarrow s_k <=> s^{c2}$ where

$s^{c2} <=> \dfrac{1}{2} \Leftrightarrow \gamma >=< \gamma^{c3}$. Note that the critical value, s^{c2}, is always greater than $1/(n+1)$.

b) $\dfrac{dq_i}{d\beta_k} = \dfrac{\gamma^{1/2}\chi^{-1/2}}{2(n+1)}\dfrac{\partial\chi}{\partial\beta_k}\{(n+1)\beta_i - \sum_{j=1}^{n}\beta_j\} - \dfrac{(\gamma\chi)^{1/2}}{(n+1)}$

$= \dfrac{(\gamma\chi)^{1/2}}{2(n+1)s_k}[\{(n+1)s_i - 1\}\dfrac{\beta_k}{\chi}\dfrac{\partial\chi}{\partial\beta_k} - 2s_k] = -\dfrac{(\gamma\chi)^{1/2}}{2(n+1)s_k}[\{(n+1)s_i - 1\}\varepsilon_{\chi k} + 2s_k]$

Since $\varepsilon_{xk} > 0$, $dq_i/d\beta_k < 0$ if $s_k > 1/(n+1)$

However, if $s_i < 1/(n+1)$, $dq_i/d\beta_k >=< 0 \Leftrightarrow \varepsilon_{\chi k} >=< 2s_k/\{1 - (n+1)s_i\}$

Replacing ε_{xk} with the expression in Definition 2 yields $dq_i/d\beta_k >=< 0 \Leftrightarrow s_i <=> s^{c0}$

c) $\dfrac{dQ}{d\beta_k} = \dfrac{(\gamma\chi)^{1/2}}{n+1} + \dfrac{1}{n+1}\sum_{j=1}^{n}\beta_j \dfrac{\gamma^{1/2}\chi^{-1/2}}{2}\dfrac{\partial\chi}{\partial\beta_k}$

$$= \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}\{2s_k + \frac{\beta_k}{\chi}\frac{\partial\chi}{\partial\beta_k}\} = \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}\{2s_k - \varepsilon_{\chi k}\}$$

Replacing ε_{xk} with the expression in Definition 2 yields the result (see Lemma 2).

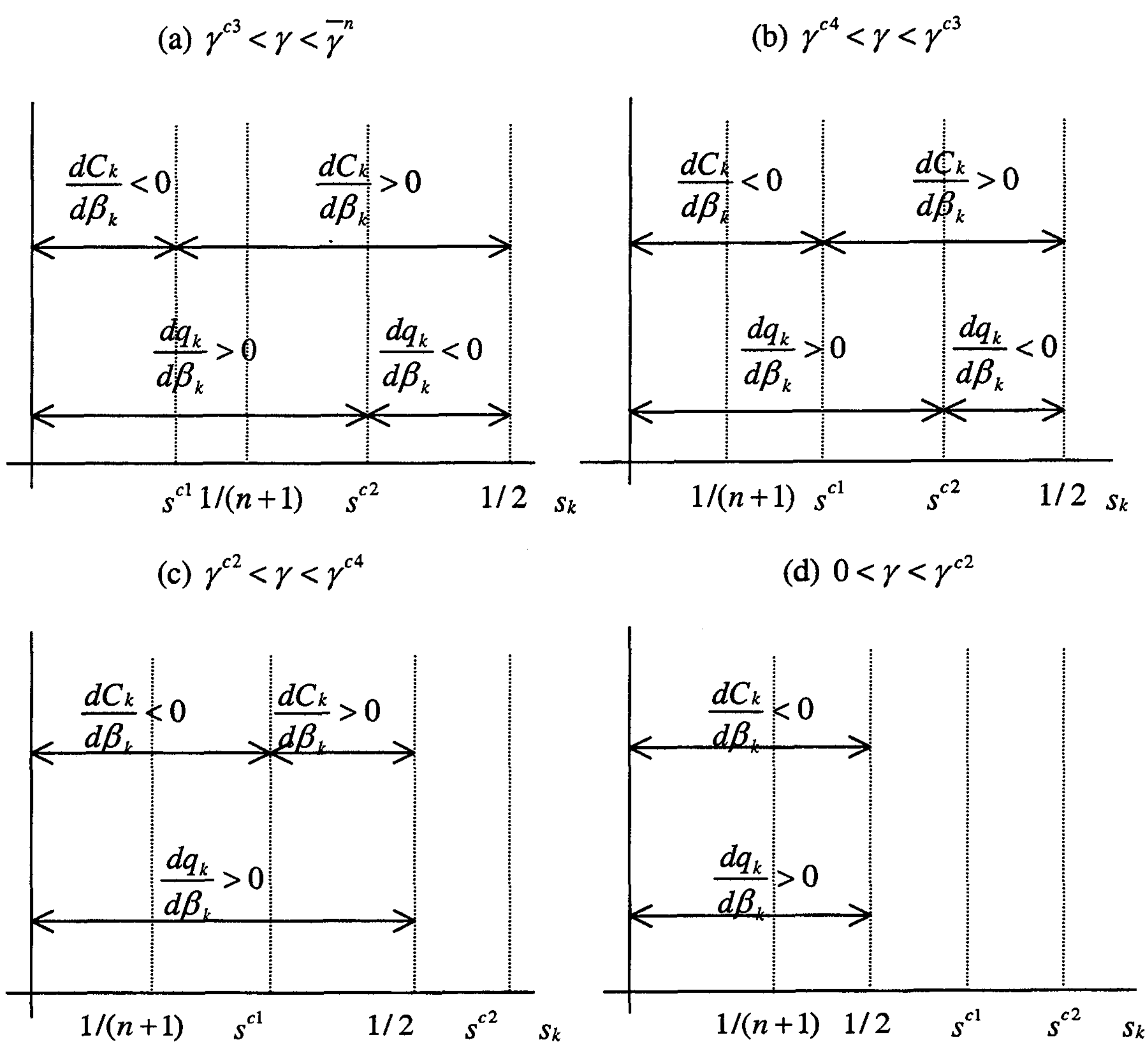

Figure 3.1 Spillover effects on the unit cost and final production[15]

[15] $\gamma^{c3} > \gamma^{c4} > \gamma^{c2} (> \gamma^{c1})$. These four graphs are drawn for a wider range of the sum of spillovers. But there is a case where we need only graph (b) if the sum of spillovers is sufficiently big (see footnote 12, 13, and 14).

Finally, the effect of relaxed IPR protection in any southern country on aggregate output is analyzed in Equation (8):

$$(8)\ \frac{dQ}{d\beta_k} = \frac{-1}{n+1}\frac{dC_k}{d\beta_k} - \frac{1}{n+1}\sum_{j\neq k}\frac{dC_j}{d\beta_k},\ k = 2,\ldots,n,\ j = 1,2,\ldots,n.$$

Since the second term on the right hand side is negative, aggregate output always decreases as long as the spillover expansion from relaxed IPR protection take place in a southern country k with spillover share, $s_k > s^{c1}$, where its unit cost increases with spillovers ($dC_k/d\beta_k > 0$). When the degree of IPR protection is lowered in southern country k with a spillover share, $s_k < s^{c1}$, the spillover effect on aggregate output will be positive only if its own effect on unit cost dominates the effect on unit costs of the other countries, that is, $|dC_k/d\beta_k| > \left|\sum_{j\neq k} dC_j/d\beta_k\right|$. We show in Lemma 4 that this case happens only if the sum of spillovers is relatively small, and R&D efficiency is sufficiently low, technically, $\sum_{j=1}^{n}\beta_j < (n+1)/2$, $\gamma < \gamma^{c1}(< \gamma^{c2})$. Under this condition, the output increases with spillovers in the southern country where spillovers take place, but decreases in the other countries. Note that the critical value of the spillover share, s^{co}, is negative under this condition (Case 2 in Table 1), which implies that the output in any southern country i, $i \neq k$, decreases with spillovers in southern country k. Also, the critical values of the spillover share, s^{c1} and s^{c2}, are bigger than ½ under this condition, which implies that the own spillover effect on unit production costs is negative while the own spillover effect on output is positive. We can summarize the spillover effects on aggregate output with the following two cases.

Table 3.1 Spillover effects on aggregate output

	Spillover effect	Condition for parameters
Case 1	$dQ/d\beta_k < 0$	$\sum_{j=1}^{n}\beta_j > (n+1)/2$ or $\sum_{j=1}^{n}\beta_j < (n+1)/2$, $\gamma > \gamma^{c1}$
Case 2	$dQ/d\beta_k > 0$	$\sum_{j=1}^{n}\beta_j < (n+1)/2$, $\gamma < \gamma^{c1}$

3.5 Welfare effects

In this section, we investigate the effect of spillovers (or IPR protection) on domestic welfare for each country. The welfare consists of firm's profits and consumer surplus for each country. The welfare of the northern country is defined by $W_1 \equiv V_1 + \theta_1 CS \equiv \pi_1 - \chi + \theta_1 CS$, where CS represents total consumer surplus. The welfare of southern country i is defined by $W_i \equiv \pi_i + \theta_i CS$, $i = 2,....,n$. The equilibrium consumer surplus and firms' profits in the final market for country i, are given by $CS_i = \theta_i Q^2/2$ and $\pi_i = q_i^2$, respectively. Thus, the signs of the effects of spillovers on consumer surplus and profit are equivalent to the signs of the effects on aggregate outputs and individual output, respectively (see Lemma 5).

Lemma 5: for $i = 1,2,....,n$, $k = 2,....,n$, and $i \neq k$,

(a) $dCS_k/d\beta_k = \theta_k Q(\partial Q/\partial \beta_k)$, $dCS_i/d\beta_k = \theta_i Q(\partial Q/\partial \beta_k)$

(b) $d\pi_k/d\beta_k = 2q_k(\partial q_k/\partial \beta_k)$, $d\pi_i/d\beta_k = 2q_i(\partial q_i/\partial \beta_k)$.

Proof) It is a straightforward result from $CS_i = \theta_i Q^2/2$ and $\pi_i = q_i^2$.

3.5.1 Northern country

The northern firm's incentive to invest in R&D decreases when IPR protection is relaxed in any southern country. The northern firm's unit cost increases, and this effect dominates the effect of the decreased R&D cost on its profit ($\dfrac{dV_1}{d\beta_k} = \dfrac{-2\gamma(A-\alpha)^2\Delta}{\{(n+1)^2 - \gamma\Delta^2\}^2} < 0, k = 2,....,n$). The sign of the spillover effect on aggregate output is equivalent to that of its effect on consumer surplus, i.e., $dQ/d\beta_k <=> 0 \Leftrightarrow dCS/d\beta_k <=> 0$. Therefore, under the condition of Case 1 the consumers in the northern country are hurt ($dCS_1/d\beta_k < 0$), thus relaxed IPR protection in any southern country hurts the northern country ($dW_1/d\beta_k < 0$).[16] Even when its consumer surplus increases with spillovers in any southern country (Case 2), only in a very restricted range the northern country will make welfare gains. We can find a critical value of the consumption share, θ_1^*, such that the northern country experiences welfare gains (loss) with spillovers in any southern country k for $\theta_1 > \theta_1^*$ ($\theta_1 < \theta_1^*$).[17] Unless R&D efficiency is close to zero and the sum of spillovers is very low, however, θ_1^* is larger than one, which implies that the northern country is hurt when IPR protection is relaxed in any southern country.

3.5.2 Southern countries

For any southern country k, the spillover expansion from relaxed IPR protection has a positive effect on the profits of its firm only if its spillover share is relatively small (i.e., $d\pi_k/d\beta_k > 0 \Leftrightarrow s_k < s^{c2}$). This is because the output increases with spillovers in these countries ($dq_k/d\beta_k > 0 \Leftrightarrow s_k < s^{c2}$). One thing to note is that the unit production cost decreases with spillovers in the countries with the spillover share, $s_k < s^{c1}(< s^{c2})$, while it increases if the spillover share is relatively big ($s_k > s^{c1}$). In this sense, the spillover expansion may be more favorable for the countries with a spillover share, $s_k < s^{c1}$. Meanwhile, relaxed IPR protection makes the firms less competitive if they are located in southern countries with a spillover share, $s_k > s^{c2}$, in the sense that their profits decrease with increased spillovers (i.e., $d\pi_k/d\beta_k < 0 \Leftrightarrow s_k > s^{c2}$). Recall that the critical value, s^{c2}, is larger than ½ as long as the R&D efficiency is sufficiently low ($\gamma < \gamma^{c4}$). If this case happens, then the spillover expansion in any southern country always yields the increased production (thus profits) of its firm (see Figure 1).

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[16] Žigić (1998) shows that the northern country is always hurt with spillovers in the southern country, especially when the duopoly turns out to be the market structure.

[17] $\theta_1^* \equiv [2\Delta\{(n+1)^2 - \gamma\Delta^2\}] \Big/ \{(\Delta - \sum_{j=1}^{n}\beta_j)(n+1) - \gamma\Delta^2\}\{n(n+1) - \gamma\Delta(\Delta-1)\}$,

$\lim_{\gamma\to 0}\theta_1^* \equiv 2\Delta \Big/ n(\Delta - \sum_{j=1}^{n}\beta_j) > 1$ for $(n+1)(n-2)/2(n-1) < \sum_{j=1}^{n}\beta_j < (n+1)/2$.

On the other hand, the cross effect of spillovers on profits is positive only for the country with a sufficiently low spillover share, i.e., $d\pi_i/d\beta_k > 0 \Leftrightarrow s_i < s^{c0}(< 1/(n+1))$. The output in these countries increases, when IPR protection is relaxed in any southern country, even though their unit production costs also increase. The intuition is that these countries become relatively competitive because the increased amount of unit costs is small compared to the countries with a larger spillover share, $s_i > s^{c0}$, i.e., $0 < dC_i/d\beta_k(s_i < s^{c0}) < dC_i/d\beta_k(s_i > s^{c0})$, $i \neq k$. However, the critical value, s^{c0}, is negative if both the degree of spillovers and R&D efficiency are sufficiently low (under Case 2: $\sum_{j=1}^{n}\beta_j < (n+1)/2$ and $\gamma < \gamma^{c1}$), which implies that the profits in any southern country i decrease with spillovers in southern country k, $k \neq i$.

Consumers are hurt when the degree of IPR protection decreases in any southern country unless both the sum of spillovers and R&D efficiency are sufficiently low (that is, under Case 1). The spillover expansion in any southern country k reduces the northern firm's incentive to invest in R&D, which consequently has a dominant effect on aggregate output. In southern country k with the spillover share $s_k < s^{c2}$ and in southern countries with spillover share $s_i < s^{c0}$, the output increases with increased spillovers in southern country k. But, in the northern country and the southern countries with spillover share $s_i > s^{c0}$, the output falls with spillovers in southern country k, and southern country k with the spillover share $s_k > s^{c2}$ also suffers from output reduction. Under the condition of Case 1, the latter effect on aggregate output dominates the former effect, i.e., $dQ/d\beta_k < 0$. Meanwhile, there is a case where consumers make gains with increased spillovers in any southern country (Case 2). This is a little bit interesting because the output decreases under the condition of Case 2 in all countries except one country where spillovers take place. The intuition is that the northern firm's reaction to relaxed IPR protection in any southern country is less sensitive if the sum of spillovers is relatively small. Thus, the spillover effect dominates the effect of the decreased R&D investment on unit costs in southern country spillovers take place. So, unit costs in southern country spillovers take place decrease while its output increases. Meanwhile, the increased amount of unit costs in the other countries becomes small because the degree of R&D efficiency is sufficiently low. Thus, the decreased output in these countries is also relatively small. Consequently, the output increase in the southern country where spillovers take place, dominates the output fall in the other countries ($dQ/d\beta_k > 0$).

Lemma-6: For $i = 1,2,\dots,n$, $k = 2,\dots,n$, and $i \neq k$

(a) $d\pi_k/d\beta_k >=< 0 \Leftrightarrow s_k <=> s^{c2}$, $d\pi_i/d\beta_k >=< 0 \Leftrightarrow s_i <=> s^{c0}$

c) $dCS_k/d\beta_k < 0$, $dCS_i/d\beta_k < 0$ if $\sum_{j=1}^{n}\beta_j > (n+1)/2$.

$dCS_k/d\beta_k <=> 0, dCS_i/d\beta_k <=> 0 \Leftrightarrow \gamma >=< \gamma^{c1}$ if $\sum_{j=1}^{n}\beta_j < (n+1)/2$

Proof) It is straightforward to show the results from Lemma 4 and Lemma 5.

The spillover effect on domestic welfare depends on both the consumption share and the spillover share. There exist two cases to be analyzed. First, suppose that aggregate output decreases with spillovers in any southern country (Case 1). Then, consumers are hurt when IPR protection is relaxed in any southern country. It is straightforward to show that the southern countries with spillover share, $s_k > s^{c2}$, are worse off by relaxed IPR protection ($dW_k/d\beta_k = d\pi_k/d\beta_k + dCS_k/d\beta_k < 0$) because the firm is also hurt ($d\pi_k/d\beta_k < 0$). Meanwhile, the profit gains in southern countries with relatively low spillover share ($s_k < s^{c2}$) come at the expense of consumers. Thus, welfare effect of spillovers in these countries depends on the consumption share (θ_k). The critical value of the consumption share, $\theta^{c1}(s_k) \equiv (\mu - \phi s_k)(\lambda + \eta s_k)$, which is a quadratic function of the spillover share, plays a crucial role in analyzing the own spillover effect on domestic welfare. If the consumption share is relatively small ($\theta_k < \theta^{c1}(s_k)$), the spillover expansion benefits southern countries. The critical value of spillover share, $\theta^{c1}(s_k)$, decreases with spillover share s_k, which reflects the fact that the profit gains from spillovers are largest in the country with the lowest spillover share. Note that it is possible to have $\mu\lambda > 1$ as $\gamma \to 0$, which implies that southern countries with very low spillover share are always better off from spillovers regardless of the consumption share.[18]

On the other hand, it is obvious that any southern country i with the spillover share, $s_i > s^{c0}$, is worse off ($dW_i/d\beta_k < 0$) when IPR protection is relaxed in southern country k, $k \neq i$ because both the firm and the consumers are hurt. For southern countries with the spillover share, $s_i < s^{c0}$, however, welfare effect depends on the consumption share. Note that the profits in these countries increase with spillovers in any given southern country. The critical value of the consumption share, $\theta^{c0} \equiv (2-\phi s_i)(\lambda+\eta s_i)$, plays a key role in examining the cross welfare effects. If consumption share is relatively big ($\theta_i > \theta^{c0}(s_i)$), compared to the spillover share, the other southern countries are worse off by relaxed IPR protection in any southern country k. That is, profit gains for these countries are overwhelmed by the decreased consumer surplus.

Lemma 6: For $i = 1,2,\ldots,n$, $k = 2,\ldots,n$, $i \neq k$

(a) Under Case 1, $dW_k/d\beta_k >=< 0 \Leftrightarrow \theta_k <=> \theta^{c1} \equiv (\mu-\phi s_k)(\lambda+\eta s_k)$, $\mu,\phi,\lambda,\eta > 0$

Under Case 2, $dW_k/d\beta_k >=< 0 \Leftrightarrow \theta_k >=< \theta^{c1} \equiv (\mu-\phi s_k)(\lambda+\eta s_k)$, $\mu,\phi < 0$, $\lambda,\eta > 0$

$$\mu \equiv \frac{2[(n\Delta+\sum_{j=1}^{n}\beta_j)(n+1)^2-\gamma\Delta^2(n\Delta-\sum_{j=1}^{n}\beta_j)]}{(\sum_{j=1}^{n}\beta_j-\Delta)(n+1)^2+\gamma(n+1)\Delta^2},\quad \phi \equiv \frac{2(n+1)\sum_{j=1}^{n}\beta_j\{(n+1)^2+\gamma\Delta^2\}}{(\sum_{j=1}^{n}\beta_j-\Delta)(n+1)^2+\gamma(n+1)\Delta^2}$$

(b) Under Case 1, $dW_i/d\beta_k >=< 0 \Leftrightarrow \theta_i <=> \theta^{c0} \equiv (2-\phi s_i)(\lambda+\eta s_i)$

Under Case 2, $dW_i/d\beta_k >=< 0 \Leftrightarrow \theta_i >=< \theta^{c0} \equiv (2-\phi s_i)(\lambda+\eta s_i)$

Proof) (a) $\dfrac{dW_k}{d\beta_k} = \dfrac{d\pi_k}{\partial\beta_k} + \dfrac{dCS_k}{d\beta_k} = 2q_k\dfrac{\partial q_k}{\partial\beta_k} + \theta_k Q\dfrac{\partial Q}{\partial\beta_k}$

[18] $\lim_{\gamma\to 0}\mu\lambda = 2(n\Delta+\sum_{j=1}^{n}\beta_j)/n(\sum_{j=1}^{n}\beta_j-\Delta) > 1$ for $(n+1)/2 < \sum_{j=1}^{n}\beta_j < 3n(n+1)/(4n-1)$. We do not consider this case in Figure 2 since it holds in a very restricted range of R&D efficiency. Meanwhile,

$$= 2q_k \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}[2n s_k - \{(n+1)s_k - 1\}\varepsilon_{xk}] + \theta_k Q \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}(2s_k - \varepsilon_{xk})$$

$$= q_k \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}[4n s_k - 2\{(n+1)s_k - 1\}\varepsilon_{xk} + \tau_k(2s_k - \varepsilon_{xk})]$$

$$= q_k \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}[2s_k(2n+\tau_k) - \{2(n+1)s_k - 2 + \tau_k\}\varepsilon_{xk}]$$

Since $\varepsilon_{\chi k} > 0$, $dW_k/d\beta_k > 0$ if $\tau_k < 2 - 2(n+1)s_k$

If $\tau_k > 2 - 2(n+1)s_k$, $dW_k/d\beta_k >=< 0 \Leftrightarrow \varepsilon_{\chi k} <=> 2s_k(2n+\tau_k)/[\tau_k + 2\{(n+1)s_k - 1\}]$

Using Definition 2 for ε_{xk} and replacing τ_k with $\tau_k \equiv \theta_k/z_k$ and $z_k \equiv q_k/Q \equiv \lambda + \eta s_k$ yields the result.

(b) $\dfrac{dW_i}{d\beta_k} = \dfrac{d\pi_i}{\partial\beta_k} + \dfrac{dCS_i}{d\beta_k} = 2q_k\dfrac{\partial q_i}{\partial\beta_k} + \theta_i Q\dfrac{\partial Q}{\partial\beta_k}$

$$= -2q_k \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}[2s_k + \{(n+1)s_i - 1\}\varepsilon_{xk}] + \theta_i Q \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}(2s_k - \varepsilon_{xk})$$

$$= -q_k \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}[4s_k + 2\{(n+1)s_i - 1\}\varepsilon_{xk} - \tau_k(2s_k - \varepsilon_{xk})]$$

$$= -q_k \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}[2s_k(2-\tau_i) + \{2(n+1)s_i - 2 + \tau_i\}\varepsilon_{xk}]$$

We examine the sign of $dW_k/d\beta_k$ with three cases.

First, if $0 < \tau_i < 2$ and $\tau_i > 2 - 2(n+1)s_i$, $dW_i/d\beta_k < 0$ since $\varepsilon_{\chi k} > 0$.

Second, if $0 < \tau_i < 2$ and $\tau_i < 2 - 2(n+1)s_i$,

$dW_i/d\beta_k >=< 0 \Leftrightarrow \varepsilon_{\chi k} >=< 2(2-\tau_i)s_k/\{2 - \tau_i - 2(n+1)s_i\}$

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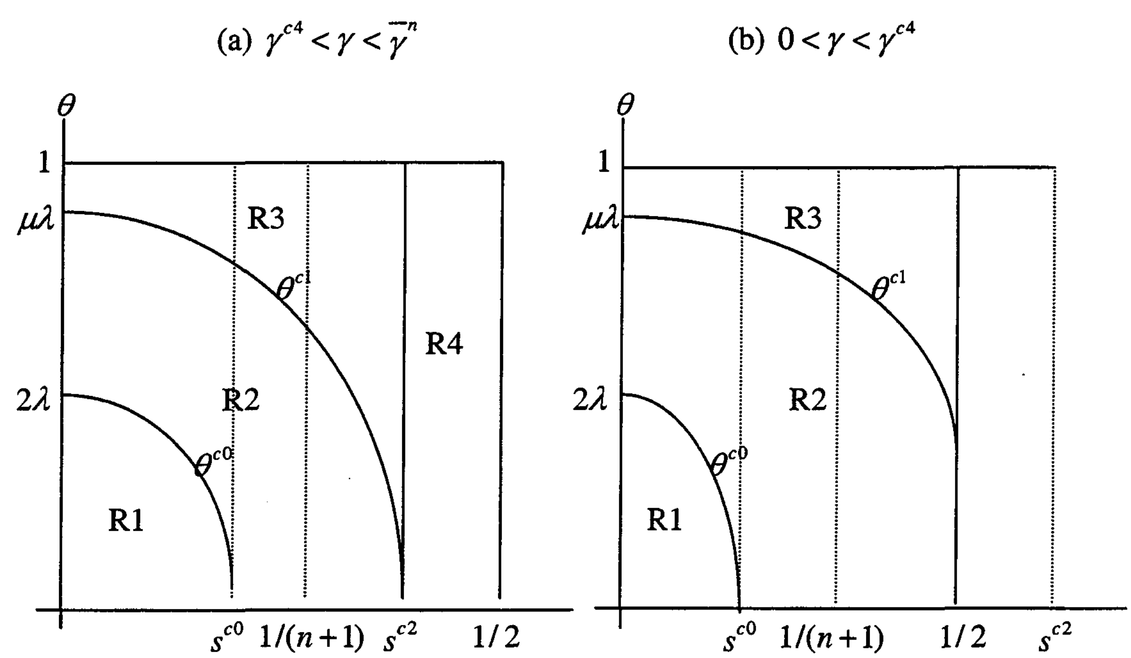
we can show that λ is always less than $1/n$ while μ is less than n for most ranges of R&D efficiency that we

Rearranging yields $dW_i/d\beta_k >=< 0 \Leftrightarrow \tau_i <=> 2-\phi s_i$

Third, if $\tau_i > 2$, $dW_i/d\beta_k >=< 0 \Leftrightarrow \tau_i <=> 2-\phi s_i$

Finally, replacing τ_i with $\tau_i \equiv \theta_i/z_i$ and $z_i \equiv q_i/Q \equiv \lambda + \eta s_i$ yields the result.



R1: $dW_k/d\beta_k > 0$, $d\pi_k/d\beta_k > 0$, $dCS_k/d\beta_k < 0$; $dW_i/d\beta_k > 0$

R2: $dW_k/d\beta_k > 0$, $d\pi_k/d\beta_k > 0$, $dCS_k/d\beta_k < 0$; $dW_i/d\beta_k < 0$

R3: $dW_k/d\beta_k < 0$, $d\pi_k/d\beta_k > 0$, $dCS_k/d\beta_k < 0$; $dW_i/d\beta_k < 0$

R4: $dW_k/d\beta_k < 0$, $d\pi_k/d\beta_k < 0$, $dCS_k/d\beta_k < 0$; $dW_i/d\beta_k < 0$

Figure 3.2 Welfare effects of spillovers under Case 1[19]

Second, suppose that aggregate output increases with spillovers in any southern country (Case 2). Then, consumers make gains when IPR protection is relaxed in any southern country. It is straightforward to show that the southern countries with the spillover

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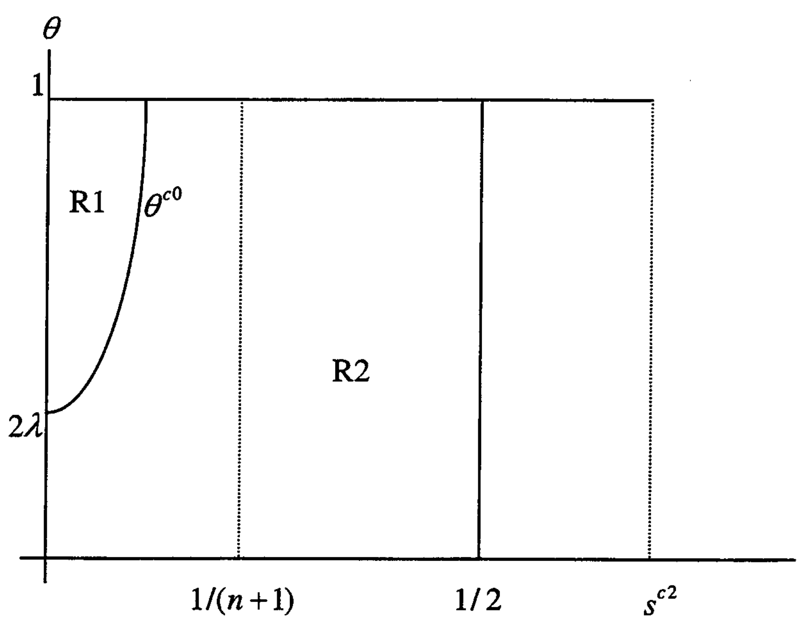
consider. Also, note that all parameters (μ, ϕ, λ, η) are positive under Case 1.

[19] Figure 2 is drawn for $\sum_{j=1}^{n} \beta_j > (n+1)/2$. However, it also holds for $\sum_{j=1}^{n} \beta_j < (n+1)/2$ and $\gamma > \gamma^{c1}$ except that the lower bound of R&D efficiency is γ^{c1} (not zero) in Figure 2 (b).

share, $s_k < s^{c2}$, are better off ($dW_k/d\beta_k > 0$) by relaxed IPR protection because the firm also makes gains ($d\pi_k/d\beta_k > 0$). The interesting thing is that under the condition of Case 2 there does not exist the southern country whose spillover share is bigger than s^{c2}, which means the own spillover effect on profits is always positive regardless of the spillover share. This is obvious technically since the critical value, s^{c2}, is bigger than 1/2, but the spillover share in any country should be less than 1/2. The economic intuition is, as long as both the sum of spillovers and R&D efficiency are sufficiently low, the northern firm is not much sensitive to the spillovers in any southern country. Thus, the direct spillover effect on its unit production costs dominates the reduced R&D investment effect. Since the output of the southern country always increase whenever its unit production costs decrease, as we showed earlier, the profit increases with spillovers in any southern country.



R1: $dW_k/d\beta_k > 0$, $d\pi_k/d\beta_k > 0$, $dCS_k/d\beta_k > 0$; $dW_i/d\beta_k > 0$

R2: $dW_k/d\beta_k > 0$, $d\pi_k/d\beta_k > 0$, $dCS_k/d\beta_k > 0$; $dW_i/d\beta_k < 0$

Figure 3.3 Welfare effects of spillovers under Case 2

On the other hand, under the condition of Case 2 the profits in any southern country i always decrease when IPR protection is relaxed in southern country k, $k \neq i$.[20] However, there exist some southern countries that they are better off with spillovers in any given southern country ($dW_i/d\beta_k > 0$) if their consumption shares are sufficiently high, i.e., $\theta_i > \theta^{c0} \equiv (2-\phi s_i)(\lambda + \eta s_i)$.[21] This is because the gains from consumers dominate the loss of the firm in these countries (see Figure 3).

3.5.3 Net trade effects of spillovers

In section 3.4, we showed that both the consumption and the production in each country change with spillovers in any southern country k. Country i's consumption is a portion (θ_i) of aggregate output. Thus, the direction of the spillover effect on consumption is the same across countries, and it is equivalent to that of its effect on aggregate output. However, the magnitude of the spillover effect on consumption is different across countries, depending on the consumption share. It is obvious that the magnitude of the consumption change is larger in the country with the larger consumption share. Meanwhile, the direction as well as the magnitude of the spillover effect on production is different across countries, depending on the spillover share. When spillovers from relaxed IPR protection take place in southern country k, its production decreases (increases) if its spillover share is sufficiently high (low), i.e., $s_k > s^{c2}$ ($s_k < s^{c2}$). The spillovers in southern country k also affect the production in any country i, where $i \neq k$. Recall that the production in country i with the spillover share $s_i < s^{c0}$ ($s_i > s^{c0}$) decreases (increases) with increased spillovers in any southern country k.

As long as there is a gap between the production and the consumption change in each country, the trade across countries must change to restore world market equilibrium. Which countries import or export depend on both the consumption share and the spillover share. To analyze the net trade effect of spillovers, we define net trade as follows:

[20] Recall that the critical value of the spillover share, s^{c0}, becomes negative under the condition of Case 2.

[21] The parameter (ϕ) becomes negative under the condition of Case 2 while parameters (λ, η)are still positive.

Definition 3: Let NT_i denote the net trade of country *i*. Then, $NT_i \equiv q_i - \theta_i Q$, $i = 1,2,\ldots\ldots,n$.

First, consider the case in which aggregate output decreases with spillovers in any southern country *k* (Case 1). The consumption in all countries decreases because of the fall of aggregate output, and the consumption reduction is larger in a country with the larger consumption share. Equation (9) analyzes the own net trade effect of spillovers:

$$(9)\ \frac{dTR_k}{d\beta_k} = \frac{dq_k}{d\beta_k} - \theta_k \frac{dQ}{d\beta_k},\ k = 2,\ldots.,n$$

Since the second term on the right hand side is positive under Case 1 ($-\theta_k dQ/d\beta_k > 0$), it is straightforward to show that the own net trade effect of spillovers is positive for southern countries with a spillover share, $s_k < s^{c2}$, because the production in these countries increases with spillovers in their countries ($dq_k/d\beta_k > 0$). The southern countries with spillover share, $s_k > s^{c2}$, may also experience a net increase in exports even though the production in their countries decreases with spillovers. This is true for southern countries whose consumption share is relatively large compared to the spillover share. In these countries the fall of consumption dominates the decreased production. We can find a critical value of the consumption share, $\theta^{c2} \equiv -\frac{1}{2}(\mu - \phi s_k)$, which is a linear function of the spillover share. As seen in Figure 4, the net trade effect of spillovers is positive (negative) in southern countries with the consumption share, $\theta_k > \theta^{c2}(s_k)$ ($\theta_k < \theta^{c2}(s_k)$).

The spillovers in any southern country *k* also affect the net trade of other countries. This cross effect of spillovers on net trade is analyzed in Equation (10)

$$(10)\ \frac{dTR_i}{d\beta_k} = \frac{dq_i}{d\beta_k} - \theta_i \frac{dQ}{d\beta_k},\ i = 1,2,\ldots.,n,\ k = 2,\ldots.,n,\ i \neq k$$

As mentioned earlier, under Case 1 consumption in any country *i* decreases with increased spillovers in southern country *k*. Thus, the cross effect of spillovers on net trade is positive for the countries with spillover share, $s_i < s^{c0}$, whose production increases with increased spillovers in southern country *k*. It is also possible that the countries with spillover share, $s_i > s^{c0}$, whose production decreases with spillovers, may have the increase of net exports.

The decreased production is overwhelmed by the fall of the consumption for the countries with the relatively big consumption share compared to the spillover share. The critical value of the consumption share, $\theta^{c3} \equiv -\frac{1}{2}(2-\phi s_i)$, plays a crucial role in investigating the cross effect of spillovers on net trade (see Figure 4).

Lemma 7: For $i = 1,2,....,n$, $k = 2,....,n$, $i \neq k$

(a) Under Case 1, $dTR_k/d\beta_k >=< 0 \Leftrightarrow \theta_k >=< \theta^{c2} \equiv -(\mu - \phi s_k)/2$, $\mu, \phi > 0$

Under Case 2, $dTR_k/d\beta_k > 0$

(b) Under Case 1, $dTR_i/d\beta_k >=< 0 \Leftrightarrow \theta_i >=< \theta^{c3} \equiv -(2-\phi s_i)/2$

Under Case 2, $dTR_i/d\beta_k < 0$

Proof) (a) $\dfrac{dTR_k}{d\beta_k} = \dfrac{dq_k}{\partial\beta_k} - \dfrac{d\theta_k Q}{d\beta_k}$

$$= \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}[2n s_k - \{(n+1)s_k - 1\}\varepsilon_{xk}] - \theta_k \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}(2 s_k - \varepsilon_{xk})$$

$$= \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}[\theta_k(\varepsilon_{xk} - 2 s_k) + 2n s_k - \{(n+1)s_k - 1\}\varepsilon_{xk}]$$

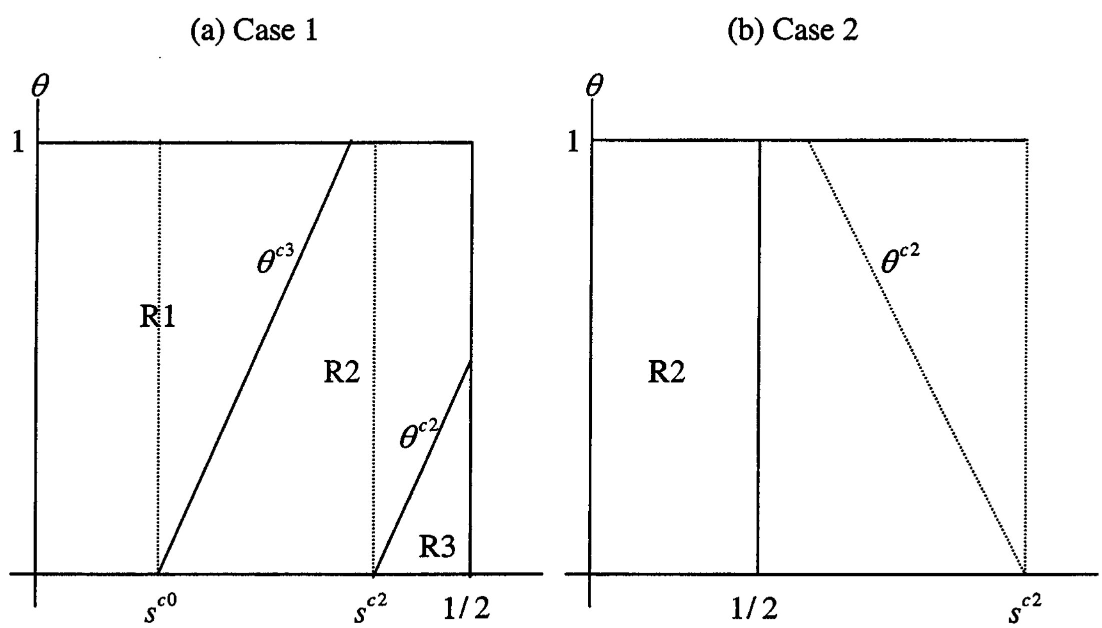
Using Definition 2 for ε_{xk} yields the result.

(b) $$\frac{dTR_i}{d\beta_k} = \frac{dq_i}{\partial\beta_k} - \frac{d\theta_i Q}{d\beta_k} = -\frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}[2 s_k + \{(n+1)s_i - 1\}\varepsilon_{xk}] - \theta_i \frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}(2 s_k - \varepsilon_{xk})$$

$$= -\frac{(\gamma\chi)^{1/2}}{2(n+1)s_k}[\theta_i(\varepsilon_{xk} - 2 s_k) + 2 s_k + \{(n+1)s_i - 1\}\varepsilon_{xk}]$$

Using Definition 2 for ε_{xk} yields the result.

On the other hand, under the condition of Case 2 aggregate output increases when IPR protection is relaxed in any southern country. Thus, the consumption in any country increases, and the increased amount of the consumption is larger in the country with the larger consumption share. Meanwhile, under the condition of Case 2 the production increases in the southern country that IPR protection is relaxed, but decreases in the other countries. Therefore, regardless of the consumption share or the spillover share, it is obvious that the country in which increased spillovers has net exports increase, while the others experience a decline in net exports.



R1: $dTR_k/d\beta_k > 0$, $dTR_i/d\beta_k > 0$, R2: $dTR_k/d\beta_k > 0$, $dTR_i/d\beta_k < 0$

R3: $dTR_k/d\beta_k < 0$, $dTR_i/d\beta_k < 0$

Figure 3.4 Net trade effect of spillovers

3.5.4 Implications and discussions

The preference towards IPR protection will be different among southern countries depending on both the consumption and the spillover share. By our analysis, southern countries can be classified into three groups in terms of the welfare effects of spillovers. Two critical values of consumption share, which are quadratic functions of the spillover share, play a crucial role in classifying southern countries: $\theta^{c1} \equiv (\mu - \phi s_k)(\lambda + \eta s_k)$ and $\theta^{c0} \equiv (2 - \phi s_k)(\lambda + \eta s_k)$, where $\theta^{c1} > \theta^{c0}$ for any given s_k. The first group consists of southern countries with $\theta < \theta^{c0}(s_k)$. This group prefers relaxing IPR protection in all southern countries ($dW_k/d\beta_k > 0$ and $dW_i/d\beta_k > 0$). The positive own (also cross) effects of spillovers on profits dominate the negative effects on consumer surplus in these countries ($|d\pi_k/d\beta_k| > |dCS_k/d\beta_k|$ and $|d\pi_i/d\beta_k| > |dCS_i/d\beta_k|$).

The second group consists of southern countries with $\theta^{c0} < \theta < \theta^{c1}$. The governments in this group prefer loose IPR protection in their own countries, but they would resist it in other southern countries ($dW_k/d\beta_k > 0$ and $dW_i/d\beta_k < 0$). The own effect of spillovers on profits is positive, and it dominates the negative effect on consumer surplus ($|d\pi_k/d\beta_k| > |dCS_k/d\beta_k|$). However, the countries in this group are worse off when IPR protection is relaxed in other southern countries because both the profit and the consumer surplus effects of spillovers in the other countries are negative for these countries. Finally, the southern countries with $\theta > \theta^{c1}$ can be classified as the third group. This group would prefer tightening IPR protection in all southern countries ($dW_k/d\beta_k < 0$ and $dW_i/d\beta_k < 0$).[22] Both the profit and consumer effects of spillovers are negative for this group no matter what spillovers take place in this group or in the other groups.

How can the conflicts between the northern country and southern countries or among southern countries be resolved? It may be difficult to find a solution as long as the three groups coexist in the world market.[23] The third group should provide more IPR protection because the countries in this group are always better off by tightening IPR protection. If all southern countries in the market are categorized in this group, therefore, there cannot exist conflicts between the North and South. In this sense, the previous result[24] that the conflicts between the North and South would be the rule may not be true. On the

[22] Under Case 2, this group doesn't exist in the world market.
[23] Given that the sum of the consumption share is one, it is possible that three groups coexist in the world market (see Figure 2). However, it is also possible that one group or two groups exist depending on how big the consumption share of each southern country is.
[24] Both Chin and Grossman (1988) and Žigić (1998) derive the conflicts between the North and the South when the market turns out to be duopoly.

other hand, the first group would vote for loose IPR protection in the southern countries since spillovers through relaxing IPR in any southern country are favorable for these countries in terms of domestic welfare. The countries in the second group prefer relaxing IPR in their countries, but tightening in the other groups. Therefore, it does not seem possible to completely resolve the conflicts between the North and the South or among the southern countries with the coexistence of the three groups in the market. Extending the tight IPR protection to all southern countries benefits the third group, but hurts the first group. Its effect on the second group would be negative if the own welfare effect of spillovers dominates the positive cross welfare effect. If the cross welfare effects of spillovers can be ignored in the WTO meeting, it is obvious that the third group should provide more IPR protection while the first and the second groups provide less IPR protection.

Table 3.2 Summary of spillover effects[25]

	Case 1 ($dQ/d\beta_k < 0$)	Case 2 ($dQ/d\beta_k > 0$)
Profits	$d\pi_k/d\beta_k >=< 0 \Leftrightarrow s_k <=> s^{c2}$ $d\pi_i/d\beta_k >=< 0 \Leftrightarrow s_i <=> s^{c0}, s^{c0} < s^{c2}$	$d\pi_k/d\beta_k > 0$, $d\pi_i/d\beta_k < 0$
Consumer surplus	$dCS_k/d\beta_k < 0$, $dCS_i/d\beta_k < 0$	$dCS_k/d\beta_k > 0$, $dCS_i/d\beta_k > 0$
Welfare	$dW_k/d\beta_k >=< 0 \Leftrightarrow \theta_k <=> \theta^{c1}(s_k)$ $dW_i/d\beta_k >=< 0 \Leftrightarrow \theta_i <=> \theta^{c0}(s_i)$	$dW_k/d\beta_k > 0$ $dW_i/d\beta_k >=< 0 \Leftrightarrow \theta_i >=< \theta^{c0}(s_i)$
Net trade	$dTR_k/d\beta_k >=< 0 \Leftrightarrow \theta_k <=> \theta^{c2}(s_k)$ $dTR_i/d\beta_k >=< 0 \Leftrightarrow \theta_i <=> \theta^{c3}(s_i)$	$dTR_k/d\beta_k > 0$ $dTR_i/d\beta_k < 0$

[25] For parameter conditions of both Case 1 and Case 2, see Table 1.

3.6 Conclusion

This chapter has investigated welfare effects of spillovers due to relaxed IPR protection. Unlike previous studies where two countries, North and South, are modeled, we consider the situation where there exist many southern countries in the market. One important feature in the model is to distinguish southern countries according to the absorptive capacity to realize spillovers. This is crucial in analyzing the conflicts among southern countries on IPR protection issue. Assuming that the differentiated policy on IPR protection can be made through the international meeting under the WTO, we ask which southern countries should provide more or less IPR protection.

Some findings are obtained from the analysis. The spillovers in any southern country from relaxing IPR protection may reduce or raise the firm's unit production cost, depending on its spillover share. The firm makes profit gains whenever its unit production cost decrease with spillovers. There is a possibility that the profit effect of spillovers is also positive even when its unit production costs increase. This happens when the R&D efficiency of the northern firm is sufficiently low or if its spillover share is not too big. However, the profit gains come at the expense of consumers because spillovers in any southern country result in a reduction of aggregate output.

The welfare effects of spillovers depend on both the consumption share and the spillover share. The southern countries can be classified into three groups in terms of the welfare effects of spillovers. The first group consists of countries with both sufficiently low spillover and consumption shares. The countries in this group are better off from relaxing IPR protection both in their countries and in other countries. The second group consists of countries whose spillover share is sufficiently low and consumption share is intermediate, or the countries where both consumption and spillover share is not too big. The countries in this group are better off from increased spillovers in their country, but worse off from spillovers in other countries. Finally, the third group may consist of three types of southern countries: countries with relatively low spillover share but high consumption share, countries with intermediate spillover share and relatively big consumption share, or countries with sufficiently high spillover share. This group suffers a welfare loss when the degree of IPR protection decreases in any southern country.

As long as all southern countries belong in the third group, the previous result that the conflict between the North and the South is the rule, is not true. Tightening IPR protection benefits both the northern country and southern countries. As long as all three groups coexist in the market, however, the conflicts on IPR protection between the North and the South as well as among southern countries cannot be completely resolved. Extending tight IPR protection to the world benefits the third group, but hurts the first group while it may or may not hurt the second group.

There are some extensions of this study. How much each country absorbs the knowledge or information from the other country depends on its ability or capacity to realize knowledge spillovers. Thus, introducing costly spillovers will be more interesting and realistic. Second, the existence of spillovers may increase the northern firm's incentive to sell its innovations to the southern countries. Thus, the issue of licensing will be an important topic as future research. Third, the direct extension of this chapter would be to investigate optimal patent policy in terms of domestic welfare or how to reach an agreement of IPR protection that is Pareto improving. Finally, some developing countries have rapidly increased R&D investment for the development of new products. Future research should include R&D investment of southern countries.

CHAPTER 4. RESEARCH JOINT VENTURES AS A TOOL OF STRATEGIC TRADE POLICY

4.1 Introduction

The welfare effects of R&D cooperation under the presence of technological involuntary spillovers have been extensively studied in a closed economy context (for example, see d'Aspremont and Jacquemin (1988), Kamien et al. (1992)). The main result is that the R&D cooperation through forming an RJV may yield the best outcome, in terms of firms' profit as well as social welfare (Kamien et al. (1992)). One limitation of these works is that spillovers (information sharing) within a research joint venture (RJV) are treated as exogenous and beyond the control of firms.

Unlike previous studies, we introduce endogenous spillovers within an RJV.[1] To increase the degree of information sharing, the firms under the RJV incur spillover costs. These costs may include management or monitoring costs to maintain an RJV.[2] Also, spillover costs may be small for the R&D intensive industry because one firm's ability to absorb or assimilate the rival firm's knowledge is likely to depend on its own R&D investment (Cohen and Levinthal (1989), Levin et al. (1987)). We show that the degree of information sharing within an RJV depends on the spillover costs.

One motivation of introducing endogenous spillovers is to see if firms may have an incentive to affect final market competition by controlling the degree of information sharing.[3] In the United States, the passage of the National Cooperative Research Act (NCRA) in 1984 seemed to promote R&D joint projects.[4] However, antitrust authorities are still concerned about the competition effect that the RJV may have on the final market since there remains a

[1] The only three papers, which consider the R&D cooperation game where firms choose the degree of spillovers, are Katz (1986), Katsoulacos and Ulph (1998), and Poyago-Theotoky (1999).
[2] Note that spillover costs may reflect systematic obstacles like organizational differences among the firms as well as actual monetary costs to acquire and assimilate rival firm's knowledge.
[3] Katsoulacos and Ulph (1998) show that for the product innovation and Bertrand competition non-maximal (partial) spillovers are chosen under the RJV, which is due to anticompetitive reasons.
[4] In Europe, the block exemption from article 85 under the Treaty of Rome corresponds to NCRA in USA.

possibility that any economic agreement may behave like a cartel.[5] Actually, the RJV is recognized as a cartel in the R&D literature dealing with spillovers in the sense that it has uniformly assumed the joint profit maximization under the RJV at the investment stage.[6] Nevertheless, any anticompetitive outcome under the RJV is ignored since the literature usually focuses on examining the positive effect of RJVs on innovative or economic performance.[7] In this chapter, we show that the RJV may yield the anticompetitive outcome, and we identify when antitrust authorities should be concerned about these outcomes.[8]

The main contribution of this chapter is to examine welfare implications of the RJV in an international economy. We combine the analysis of the R&D cooperation with strategic trade policy theory. The key question is whether the government should allow its domestic firms to form an RJV. Motta (1996) and Steurs (1997) are the only two papers where similar questions are addressed. They investigate the role of the RJV in an international market. One important difference between our model and theirs is that they assume that the degree of information sharing under the RJV is exogenously given while we focus on examining how spillovers are determined within an RJV. The study in this chapter is possibly related to Qiu and Tao's paper (1998). They investigate the role of the government's R&D policy when a domestic firm cooperates with its foreign rival in the R&D activity. While they examine the optimal policy on R&D cooperation we consider 'allowing an RJV formation' as the only possible policy, and investigate whether it is beneficial in terms of domestic welfare.

We extend d'Aspremont and Jacquemin's (1988) model to examine the welfare implications of the RJV in an international economy.[9] There are two countries (home and foreign) and each country consists of two firms (firm i and firm j). Firms are ex-ante identical. We consider three games: Game $N\overline{N}$, Game $J\overline{N}$ (or $N\overline{J}$), and Game $J\overline{J}$. Each game consists of two stages, R&D and output stage. In a final market (output stage) four firms

[5] Ordover and Willig (1985) suggest a special treatment of RJVs and horizontal mergers in the R&D intensive industry under the antitrust laws.
[6] It is briefly mentioned below that the joint profit maximization under the RJV may not make sense.
[7] One exception we recognize is Katsoulacos and Ulph (1998) (see footnote 3).
[8] These implications can be obtained even though we consider an international market.
[9] While d'Aspremont and Jacquemin's (1988) model is usually used to explain the role of the involuntary spillovers, we assume away the existence of the involuntary spillovers to focus on examining the role of the RJV as a policy tool in an international economy when spillovers are endogenously determined under the RJV. Note that introducing involuntary spillovers does not qualitatively affect our results.

compete with a homogenous good. A final market may be a 'third-market' or an integrated market.[10] In the R&D stage, the firms engage in R&D activities whose benefit is to lower marginal production costs. The way to coordinate R&D activities is to form an RJV. Under the RJV, firms choose the degree of information sharing as well as R&D efforts to maximize joint profits. We consider only the national RJV, not the international RJV. This is because we want to see whether an RJV may work as a tool of strategic trade policy.

Table 4.1 Summary of the game

Game	R&D stage	Output stage
$N\overline{N}$	- All firms choose R&D efforts non-cooperatively to maximize own profits. - No firm can share its rivals' knowledge.	Cournot competition
$J\overline{N}$	- The RJV is formed only in the home country. - Home firms choose both R&D efforts and the degree of information sharing (spillovers) simultaneously to maximize joint profits under the RJV. - Foreign firms decide R&D levels to maximize own profits. - Home (RJV) and foreign firms compete non-cooperatively	Cournot competition
$J\overline{J}$	- The RJV is formed in each country (two RJVs). - The firms choose both R&D efforts and the degree of information sharing simultaneously to maximize joint profits under the RJV in each country. - Home and foreign firms (RJVs) compete non-cooperatively	Cournot competition

The games differ in whether firms choose to cooperate in the R&D stage. In the game $N\overline{N}$, each firm chooses R&D efforts non-cooperatively to maximize its own profits. No firm in this game can share its rivals' knowledge. This game serves as the benchmark when we analyze the welfare effects of research joint ventures. In the game $J\overline{N}$ ($N\overline{J}$), only

[10] The analysis of the integrated market gives welfare implications of the RJV consisting of some (not all) firms in the industry in a closed economy. Note that the literature usually assumes an industry-wide RJV.

the home (foreign) firms form an RJV while the foreign (home) firms do not. The firms in the home (foreign) country choose the degree of information sharing as well as R&D efforts to maximize joint profits. Meanwhile, the firms in the foreign (home) country choose R&D efforts non-cooperatively to maximize own profits. In the game $J\overline{J}$, the firms in both the home and foreign countries form an RJV in each country. Since we only consider a national RJV, firms from different countries always compete non-cooperatively in the R&D stage regardless of the game. Note that we assume the RJV formation is an exogenously given policy by the government.[11]

Each stage consists of a simultaneous game. We try to derive the Nash equilibrium(a) in every stage, and finally identify the sub-game perfect Nash equilibrium (SPNE). We show that the firms under the RJV do not share any information if spillover costs are sufficiently high while they choose maximal spillovers within an RJV if spillover costs are sufficiently low.[12] The minimal spillovers are chosen due to the anticompetitive effect. This result contrasts with previous studies where complete information sharing (spillovers) within an RJV is usually assumed. We also find that there are multiple Nash equilibria(NEa). Under the game $J\overline{N}$, minimal or maximal spillovers are chosen within an RJV when spillover costs lie in an intermediate range. Meanwhile, under the game $J\overline{J}$, asymmetric spillovers between the two countries (RJVs) turn out to be the Nash equilibria for a moderate range of spillover costs.

To provide the answer as to whether any government should allow its domestic firms to form an RJV, we consider two market structures: a 'third market' and an integrated market. We show that many results obtained in the third market structure become reversed in the integrated market structure. For example, under the game $J\overline{N}$, if spillover costs are sufficiently high ($k > k^2$) then the home country is better off by allowing an RJV in the third market structure, but RJV formation hurts the home country in the integrated market

[11] We also assume that the firms join in an RJV whenever the government allows an RJV formation. Introducing the firms' decision stage as to whether to join in an RJV does not qualitatively change the results, but makes the analysis very complex.

[12] The corner solution of spillovers ($\beta = 0, \beta = 1$) is due to the assumption of linear spillover costs. With quadratic form of spillover costs we can get partial spillovers ($0 < \beta < 1$). What we want to investigate is whether the maximal spillovers within an RJV always occur.

structure. This is basically due to the home firms' choice of spillovers under the RJV. They choose symmetric minimal spillovers, which yields the increased final market price. The home firms' profits increase, but the consumer surplus decreases. The consumer loss dominates the increased home firms' profits. We also identify when the foreign country has an incentive to retaliate for the home country's RJV formation, and investigate the welfare implications when both the home and foreign countries allow an RJV formation in each country.

This paper is organized as follows. Section 2 provides a brief literature review on R&D cooperation and strategic trade policy. Section 3 sets up the model and identifies the Nash equilibria both in the R&D and output stage. Section 4 compares R&D outcomes and final outputs among the considered games. Section 5 provides welfare implications of the RJV (R&D cooperation) in an international economy. The last section provides conclusions.

4.2 Literature Review

A country has many instruments with which to conduct trade policy. For example, export subsidies or taxes can be directed towards production, while R&D subsidies or taxes can be directed towards innovation. However, the former measures are increasingly difficult for governments to pursue because they are strictly forbidden by the WTO. This leads to a need for further analysis of trade policy measures directed towards innovation. Besides, the merits of subsidizing exporting firms have to be reexamined in terms of one key consideration in the recent R&D literature: the benefit of forming a research joint venture (see Kamien et al. (1992)).

The welfare implications of RJVs in open economies have been little studied. Only some studies, recently, have dealt with the role of the R&D cooperation (or research joint ventures) in the presence of international competition. Motta (1996), Steurs (1997), Qiu and Tao (1998), and Neary and O'Sullivan (1999) combine the analysis of the R&D cooperation with the strategic trade policy theory.[13]

Motta (1996) and Steurs (1997) extended the d'Aspremont and Jacquemin's (1988)

[13] See Brander (1995) for an excellent survey of strategic trade policy literature

model to study the effect of research joint ventures as a policy tool in an international economy. Both of them consider the case of two symmetric firms each located in a different country. The spillover parameter is exogenously given. Motta assumes that firms can achieve complete information sharing within an RJV while the degree of spillovers does not change with R&D cooperation in Steurs. One interesting result is that, contrary to other trade policies, which lead to a prisoner's dilemma result, welfare in both countries increases when they both allow R&D cooperation (Motta). An even more surprising result is that when national R&D cooperation results in higher welfare for the cooperating country, this may be also true for the non-cooperating country (Steurs). In this paper, we show that these results may not hold if the degree of information sharing is endogenously determined.

In Neary and O'Sullivan (1999) firms face exogenously given spillovers, and spillovers do not change with R&D cooperation. A domestic and a foreign firm export a homogenous good to a third market. They study international R&D cooperation with export subsidization both in general, and for specific functional forms. The main results of Neary and O'Sullivan are summarized as follows. First, an export subsidy may increase welfare relative to R&D cooperation if the government can commit to an export subsidy. Second, without commitment, subsidization may yield welfare levels much lower than cooperation and lower even than free trade.

Qiu and Tao (1998) study the role of the government's R&D policy when a domestic firm cooperates with its foreign rival in the R&D activity. Two types of R&D cooperation are examined: 'Collaboration and coordination'. In the case of the R&D collaboration, the two firms share the benefits of their R&D investments in that firm i's unit cost of production depends on its own R&D investment and firm j's investment. Meanwhile, in the case of the R&D coordination each firm chooses its R&D investment to maximize a weighted joint profit (i.e., $\pi_i + \alpha\pi_j, 0 \le \alpha \le 1$). Qiu and Tao show that R&D subsidy is an optimal policy in the latter case while R&D subsidy or tax are possible in the former case. Our work differs from Qiu and Tao's in the sense that we consider 'allowing an RJV formation' as the only possible policy. While we recognize the need to examine the optimal policy on R&D cooperation we also believe whether allowing an RJV formation is a desirable policy should be addressed first to avoid ambiguous policy suggestions.

4.3 The Model and Equilibrium

4.3.1 The Model

We consider a model where two countries (home and foreign country) compete in an international market. Two firms (firm 1 and firm 2) exist in each country. In a final market, four firms sell a homogenous product, whose inverse demand is given by $P = A - Q$, $Q = \sum_i (q_i + \bar{q}_i)$, $i = 1,2$. q_i and $\bar{q}_i$ denote the final output production for firm i located in the home and foreign country, respectively. We use an upper bar to denote variables associated with the foreign country. In a previous stage, each firm invests in R&D to reduce its unit production cost, which is a function of its own R&D investment, rival firm's R&D investment, and spillovers so that firm i's unit production cost is written by

(1) $C_i = c - \chi_i - \beta_i \chi_j, \bar{C}_i = c - \bar{\chi}_i - \bar{\beta}_i \bar{\chi}_j$ where, $0 \leq \beta_i, \bar{\beta}_i \leq 1$, $i, j = 1,2$, $i \neq j$.

$\chi_i(\bar{\chi}_i)$ represents R&D investment of firm i located in the home (foreign) country. β denotes the degree of spillovers (information sharing) between the firms within an RJV. The firm in any country benefits from the other national, but not international, firm's knowledge since we consider only the national research joint venture. We assume away involuntary information spillovers since we focus on examining how the degree of information within an RJV is determined in the economy.[14] R&D technology exhibits diminishing returns to scale to R&D investment so that its cost is written by $TC_i(\chi_i) = \gamma \chi_i^2 / 2$, $\bar{TC}_i(\bar{\chi}_i) = \gamma \bar{\chi}_i^2 / 2$ for the home and foreign firms, respectively. γ denotes R&D efficiency. A higher γ implies lower R&D efficiency. As seen in the unit production function, we assume that the degree of spillovers from which the firm benefits is determined by its own ability to absorb or assimilate rival firm's R&D knowledge (Cohen and Levinthal 1989). Each firm that absorbs the rival firm's knowledge incurs costs, which depend on the amount of information sharing.[15] We assume that this cost increases with the

[14] Griliches (1995) provides an excellent review of empirical studies for the existence of involuntary R&D spillovers. Introducing involuntary spillovers does not qualitatively change key results obtained in this chapter.
[15] Vilasuso and Frascatore (2000) introduce a costly RJV in which firms face costs depending on the degree of spillovers even though they assume spillovers are exogenously given.

amount of knowledge absorbed so that this spillover (or information sharing) cost for the home and foreign firms can be written by $K_i = k\beta_i$ and $\overline{K}_i = k\overline{\beta}_i$, $i = 1,2$. These costs may be smaller if the industry is R&D intensive because one firm's ability to absorb or assimilate rival firm's knowledge is likely to depend on its own R&D investment.[16] Thus, k may be industry specific as well as firm specific.

Table 4.2 Notational definitions

Game	Equilibrium per firm profit, consumer surplus, and welfare	
	Home Country	Foreign Country
$N\overline{N}$	$V^{N\overline{N}}, \alpha CS^{N\overline{N}}, W^{N\overline{N}}$	$\overline{V}^{N\overline{N}}, \overline{\alpha} CS^{N\overline{N}}, \overline{W}^{N\overline{N}}$
$J\overline{N}$	$V^{J\overline{N}}, \alpha CS^{J\overline{N}}, W^{J\overline{N}}$	$\overline{V}^{J\overline{N}}, \overline{\alpha} CS^{J\overline{N}}, \overline{W}^{J\overline{N}}$
$J\overline{J}$	$V^{J\overline{J}}, \alpha CS^{J\overline{J}}, W^{J\overline{J}}$	$\overline{V}^{J\overline{J}}, \overline{\alpha} CS^{J\overline{J}}, \overline{W}^{J\overline{J}}$

Table 2 defines some notations used in the paper. V denotes the equilibrium per firm profit (final stage profit - R&D cost). CS denotes total consumer surplus. In an integrated market, the home country consumes α portion of total consumption while the foreign country consumes $\overline{\alpha}$ portion of total consumption. Thus, the consumer surplus for the home and foreign country is denoted by αCS and $\overline{\alpha} CS$, respectively. W and $\overline{W}$ denote the domestic welfare for the home and foreign country, respectively.

4.3.2 Equilibrium

The nature of the equilibrium is the sub-game perfect Nash equilibrium. As usual, we solve the two-stage game using backwards induction. First, we solve for the Nash equilibrium in a final market. Second, the R&D levels and the degree of information sharing (under the RJV) under all three games are determined.

In the final stage, the firms face Cournot competition regardless of the game. Each firm chooses quantity to maximize its own profits (i.e., $\pi_i = P(Q)q_i - C_i q_i$), given the

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[16] Kogut (1989) identifies several factors that may affect the costs associated with maintaining an RJV.

previous stage R&D investment. Solving the problem yields final stage output and profit as a function of R&D investment and spillovers:

$$(2)\ q_i = \frac{A-4C_i+C_j+\overline{C}_i+\overline{C}_j}{5},\ \overline{q}_i = \frac{A-4\overline{C}_i+\overline{C}_j+C_i+C_j}{5},\ \pi_i = (q_i)^2,\ \overline{\pi}_i = (\overline{q}_i)^2$$

where, $i \neq j$, $i = 1,2$.

In the first stage, the firms engage in the R&D non-cooperation or the R&D cooperation. The way to coordinate R&D activities is to join in an RJV, given an RJV formation is allowed by the government. We determine the R&D efforts and the degree of spillovers (under the RJV) in the next three sub-sections.

4.3.2.1 R&D Non-cooperation in both countries (game $N\overline{N}$)

Consider the game ($N\overline{N}$) where neither government allows an RJV formation. Thus, there is no way to coordinate R&D activities and to share information among firms. Hence, each firm's unit production cost is simply a function of its own R&D investment: $C_i = c - \chi_i$ and $\overline{C}_i = c - \overline{\chi}_i$ where $i = 1,2$. Each firm chooses the level of R&D investments to maximize its own profit (the final stage profit – R&D costs). The profit for the home firm i is written by

$$(3)\ V_i = \pi_i - TC_i(\chi_i) = \frac{\{A-c+4\chi_i-(\chi_j+\overline{\chi}_i+\overline{\chi}_j)\}^2}{25} - \frac{\gamma}{2}(\chi_i)^2,\ i \neq j,\ i = 1,2.$$

The first and second order conditions are as follows:

$$(4)\ \frac{\partial V_i}{\partial \chi_i} = \frac{8\{A-c+4\chi_i-(\chi_j+\overline{\chi}_i+\overline{\chi}_j)\}}{25} - \gamma\chi_i = 0,\ \frac{\partial^2 V_i}{\partial \chi_i^2} = \frac{32}{25} - \gamma < 0$$

The first and second order conditions for the foreign firms can be similarly derived. Assuming symmetric solution ($\chi_i = \chi_j = \overline{\chi}_i = \overline{\chi}_j = \chi^{N\overline{N}}$), we can get the equilibrium R&D investment: $\chi^{N\overline{N}} = \dfrac{8(A-c)}{25\gamma-8}$.[17] Finally, we can get the following outcomes under the R&D

[17] As seen in Henriques (1990), the equilibrium R&D investment under the non-cooperative game may not be stable even though the second order condition is satisfied. Using the stability condition $|\partial\chi_i/\partial\chi_j| < 1$, this is

non-cooperation:

$$\chi^{N\bar{N}} = \frac{8(A-c)}{25\gamma - 8},\ q^{N\bar{N}} = \frac{5\gamma(A-c)}{(25\gamma-8)},\ Q^{N\bar{N}} = \frac{20\gamma(A-c)}{(25\gamma-8)},\ V^{N\bar{N}} = \frac{\gamma(A-c)^2(25\gamma-32)}{(25\gamma-8)^2}$$

4.3.2.2 R&D cooperation only in one country (game $J\bar{N}(N\bar{J})$)

In this subsection, we consider the case where the firms in one country form an RJV to coordinate R&D activities while the firms located in the other country do not. To avoid notational complexity we assume that the home country is the cooperating country while the foreign country is the non-cooperating country ($J\bar{N}$). Thus, firms' unit production costs will be different between the home and foreign countries: $C_i = c - \chi_i - \beta_i \chi_j$, $\bar{C}_i = c - \bar{\chi}_i$, where $i \neq j$, $i, j = 1,2$. Recall that we do not consider an international R&D cooperation where two firms from different countries form an RJV.[18] Given the final stage profits, the home firms under the RJV maximize their joint profits while choosing the R&D investment and the amount of information sharing (β_i) simultaneously.[19] The home firms incur a spillover cost to absorb other firm's knowledge under the RJV.

The joint profit function can be written as:

$$(5)\ V^T \equiv V_i + V_j = \frac{1}{25}\{A-c+(4-\beta_j)\chi_i+(4\beta_i-1)\chi_j-\bar{\chi}_i-\bar{\chi}_j\}^2-\frac{\gamma}{2}\chi_i^2-k\beta_i$$
$$+\frac{1}{25}\{A-c+(4-\beta_i)\chi_j+(4\beta_j-1)\chi_i-\bar{\chi}_i-\bar{\chi}_j\}^2-\frac{\gamma}{2}\chi_i^2-k\beta_j$$

where, $i \neq j$, $i, j = 1,2$.

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true in our model if $\gamma < 40/25$. If the equilibrium is unstable (in Henriques' term), we may have to consider a corner solution where only one firm invests in R&D under the R&D non-cooperation game. Note that we assume $\gamma > 120/25$ to avoid unstable situations under all games considered in the paper.

[18] Steurs (1997) examines welfare effects between a domestic and an international R&D cooperation.

[19] We follow the assumption of joint profit maximation as the standard in the literature in the sense that the literature has uniformly assumed joint profit maximization under the RJV. However, whether this assumption is appropriate requires further analysis since it is difficult to believe that firms, in reality, can write the contracts to maximize joint profits when they are competitors in a final market. For example, if firm's profit is a portion of total profits under the RJV and the portion depends on its own R&D spending then it may be more profitable for the firm to deviate from joint profit max. by maximizing its own profit choosing own R&D spending. Salant and Shaffer(1998) and Anbarci et al.(2002) briefly mention this issue.

Meanwhile, the foreign firms choose R&D investments to maximize their own profits (including R&D cost), which can be written by

$$(6)\ \overline{V}_i = \frac{1}{25}\{A - c + 4\overline{\chi}_i - \overline{\chi}_j - (1+\beta_j)\chi_i - (1+\beta_i)\chi_j\}^2 - \frac{\gamma}{2}\chi_i^{\,2},\ i \neq j,\ i,j = 1,2$$

The first order conditions for joint profit maximization of the home firms are

$$(7)\ \frac{\partial V^T}{\partial \beta_i} = \frac{2}{25}\{A - c + (4-\beta_j)\chi_i + (4\beta_i - 1)\chi_j - \overline{\chi}_i - \overline{\chi}_j\}(4\chi_j)$$

$$+\frac{2}{25}\{A - c + (4-\beta_i)\chi_j + (4\beta_j - 1)\chi_i - \overline{\chi}_i - \overline{\chi}_j\}(-\chi_j) - k = 0$$

$$\frac{\partial V^T}{\partial \chi_i} = \frac{2}{25}\{A - c + (4-\beta_j)\chi_i + (4\beta_i - 1)\chi_j - \overline{\chi}_i - \overline{\chi}_j\}(4-\beta_j)$$

$$+\frac{2}{25}\{A - c + (4-\beta_i)\chi_j + (4\beta_j - 1)\chi_i - \overline{\chi}_i - \overline{\chi}_j\}(4\beta_j - 1) - \gamma\chi_i = 0$$

where, $i \neq j$, $i = 1,2$.

The second order conditions are: for $i \neq j$, $i = 1,2$

$$(8)\ \frac{\partial^2 V^T}{\partial \beta_i^{\,2}} = \frac{34}{25}\chi_j^{\,2} > 0,\ \frac{\partial^2 V^T}{\partial \beta_i \beta_j} = -\frac{16}{25}\chi_i\chi_j < 0$$

$$\frac{\partial^2 V^T}{\partial \chi_i^{\,2}} = \frac{2}{25}\{(4-\beta_j)^2 + (4\beta_j - 1)^2\} - \gamma < 0 \text{ for all } 0 \leq \beta \leq 1 \text{ if } \gamma > \frac{36}{25}$$

$$\frac{\partial^2 V^T}{\partial \chi_i \chi_j} = \frac{2}{25}\{(4-\beta_j)(4\beta_i - 1) + (4-\beta_i)(4\beta_j - 1)\}$$

Assuming that R&D investment and the spillovers are simultaneously determined, we can solve the problem. From the second order condition with respect to spillovers, we should consider corner solutions ($\beta = 0$ or $\beta = 1$). That is, the firms under the RJV will choose either minimal or maximal spillovers. Note that the corner solution of spillovers is due to the assumption of linear spillover costs.[20] This is confirmed from the fact that the

[20] The solution of spillovers will depend on the specific form of cost function. With quadratic form of spillover costs we can get the partial ($0 < \beta < 1$) or maximal ($\beta = 1$) spillovers. The main thing is to show that maximal spillovers under the RJV are not necessarily guaranteed by the existence of spillover costs.

Hessian matrix of spillovers is positive definite. That is, $H^{\beta}=\begin{bmatrix}\frac{\partial^2 V^T}{\partial\beta_i^2} & \frac{\partial^2 V^T}{\partial\beta_i\partial\beta_j}\\ \frac{\partial^2 V^T}{\partial\beta_j\partial\beta_i} & \frac{\partial^2 V^T}{\partial\beta_j^2}\end{bmatrix}$,

where $H^{\beta}_{kk}>0$, $k=i,j$ and $|H^{\beta}|=\frac{36}{25}\chi_i^{\,2}\chi_j^{\,2}>0$. Meanwhile, we can find out an interior solution of R&D investment from the first order condition. The Hessian matrix of R&D investment is negative definite, which implies that the interior solution is optimal.[21] All four firms determine the equilibrium R&D investment simultaneously. Therefore, we need to consider first order conditions of the foreign firms' profit maximization. The first and second order conditions with respect to the foreign firms' R&D investment are as follows:

(9) $\frac{\partial\overline{V}_i}{\partial\overline{\chi}_i}=\frac{8}{25}\{A-c+4\overline{\chi}_i-\overline{\chi}_j-(1+\beta_j)\chi_i-(1+\beta_i)\chi_j\}-\gamma\overline{\chi}_i=0$

$\frac{\partial^2\overline{V}_i}{\partial\overline{\chi}_i^{\,2}}=\frac{32}{25}-\gamma<0$, where $i\neq j$, $i,j=1,2$.

From the first order conditions ((7) and (9)), we get four best response functions.

(10) $\chi_i=\frac{2(A-c)(3+3\beta_j)+2B\chi_j-2(3+3\beta_j)(\overline{\chi}_i+\overline{\chi}_j)}{D}$, where $i\neq j$, $i,j=1,2$.

$B\equiv(4-\beta_j)(4\beta_i-1)+(4-\beta_i)(4\beta_j-1)$, $D\equiv 25\gamma-2\{(4-\beta_j)^2+(4\beta_i-1)^2\}$

$\overline{\chi}_i=\frac{8(Aa-c)-8\overline{\chi}_j-8(1+\beta_j)\chi_i-8(1+\beta_i)\chi_j}{25\gamma-32}$, where $i\neq j$, $i,j=1,2$.

Recalling that we have a corner solution for spillovers under the RJV (minimal spillovers $\beta=0$ or maximal spillovers $\beta=1$) and solving (10) simultaneously, we can get the following final outcomes under the game $J\overline{N}$:

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[21] $H^{\chi}_{kk}<0$ from the equation (8), and assuming symmetric spillovers we can show that $|H^{\chi}|=\gamma^2-4\gamma\{(4-\beta)^2+(4\beta-1)^2\}/25+36(1-\beta^2)^2/25>0$ if $\gamma>72/25$.

1. Firms under the RJV choose symmetric minimal spillovers ($\beta_i = \beta_j = \beta = 0$),

$$x^{J\bar{N}}(\beta = 0) = \frac{6(A-c)(5\gamma-8)}{125\gamma^2 - 210\gamma + 48}, \quad \bar{x}^{J\bar{N}}(\beta = 0) = \frac{8(A-c)(5\gamma-6)}{125\gamma^2 - 210\gamma + 48}$$

$$q^{J\bar{N}}(\beta = 0) = \frac{5\gamma(A-c)(5\gamma-8)}{125\gamma^2 - 210\gamma + 48}, \quad \bar{q}^{J\bar{N}}(\beta = 0) = \frac{5\gamma(A-c)(5\gamma-6)}{125\gamma^2 - 210\gamma + 48}$$

$$V^{J\bar{N}}(\beta = 0) = \frac{\gamma(A-c)^2(5\gamma-8)^2(25\gamma-18)}{(125\gamma^2 - 210\gamma + 48)^2}, \bar{V}^{J\bar{N}}(\beta = 0) = \frac{\gamma(A-c)^2(5\gamma-6)^2(25\gamma-32)}{(125\gamma^2 - 210\gamma + 48)^2}$$

$$Q^{J\bar{N}}(\beta = 0) = \frac{10\gamma(A-c)(10\gamma-14)}{125\gamma^2 - 210\gamma + 48}$$

2. Firms under the RJV choose symmetric maximal spillovers ($\beta_i = \beta_j = \beta = 1$),

$$x^{J\bar{N}}(\beta = 1) = \frac{12(A-c)(5\gamma-8)}{125\gamma^2 - 480\gamma + 192}, \quad \bar{x}^{J\bar{N}}(\beta = 1) = \frac{8(A-c)(5\gamma-24)}{125\gamma^2 - 480\gamma + 192}$$

$$q^{J\bar{N}}(\beta = 1) = \frac{5\gamma(A-c)(5\gamma-8)}{125\gamma^2 - 480\gamma + 192}, \quad \bar{q}^{J\bar{N}}(\beta = 1) = \frac{5\gamma(A-c)(5\gamma-24)}{125\gamma^2 - 480\gamma + 192}$$

$$V^{J\bar{N}}(\beta = 1) = \frac{\gamma(A-c)^2(5\gamma-8)^2(25\gamma-72)}{(125\gamma^2 - 480\gamma + 192)^2} - k,$$

$$\bar{V}^{J\bar{N}}(\beta = 1) = \frac{\gamma(A-c)^2(5\gamma-24)^2(25\gamma-32)}{(125\gamma^2 - 480\gamma + 192)^2}, \quad Q^{J\bar{N}}(\beta = 1) = \frac{10\gamma(A-c)(10\gamma-32)}{125\gamma^2 - 480\gamma + 192}$$

3. Firms under the RJV choose asymmetric spillovers ($\beta_i \neq \beta_j (e.g., \beta_i = 0, \beta_j = 1)$),

$$x_i^{J\bar{N}}(\beta_i = 0, \beta_j = 1) = \frac{12(A-c)(\gamma-1)(5\gamma-8)}{125\gamma^3 - 470\gamma^2 + 420\gamma - 96},$$

$$x_j^{J\bar{N}}(\beta_i = 0, \beta_j = 1) = \frac{6(A-c)\gamma(5\gamma-8)}{125\gamma^3 - 470\gamma^2 + 420\gamma - 96},$$

$$\bar{x}^{J\bar{N}}(\beta_i = 0, \beta_j = 1) = \frac{8(A-c)(5\gamma^2 - 20\gamma + 12)}{125\gamma^3 - 470\gamma^2 + 420\gamma - 96},$$

$$V^{J\bar{N}}(0,1) = \frac{(A-c)^2\gamma(625\gamma^5 - 5800\gamma^4 + 18960\gamma^3 - 28168\gamma^2 + 19072\gamma - 4608)}{(125\gamma^3 - 470\gamma^2 + 420\gamma - 96)^2},$$

$$V^{J\overline{N}}(1,0)=\frac{(A-c)^2\gamma^2(625\gamma^4-2950\gamma^3+4740\gamma^2-2752\gamma+256)}{(125\gamma^3-470\gamma^2+420\gamma-96)^2}-k$$

To examine when the firms under the RJV choose minimal, maximal, or asymmetric spillovers we need to compare joint profits: $V^{J\overline{N}}(\beta_i=\beta_j=0)$, $V^{J\overline{N}}(\beta_i=\beta_j=1)$, and $V^{J\overline{N}}(\beta_i=0,\beta_j=1)$. The home firms choose the degree of information sharing within an RJV simultaneously. Each firm has two strategies of spillovers: $\beta=0$, $\beta=1$. Anticipating what strategies the other firm under the RJV will play, each firm selects its best strategy. Based on the payoff for each strategy, we can derive the Nash equilibria in this stage.

Table 4.3 ($V_i(\beta_i,\beta_j),V_j(\beta_i,\beta_j)$) in firms' decision of spillovers under the game $J\overline{N}$

	$\beta_j=0$	$\beta_j=1$
$\beta_i=0$	$V_i(0,0)$, $V_j(0,0)$	$V_i(0,1)$, $V_j(0,1)$
$\beta_i=1$	$V_i(1,0)$, $V_j(1,0)$	$V_i(1,1)$, $V_j(1,1)$

Note that we consider the games of complete information in the sense that the players know all relevant information, including spillover costs, payoffs, etc. Three kinds of Nash equilibria exist depending on spillover costs (see result 1).[22]

Firstly, if spillover costs are sufficiently high ($k>k^1$), then both firms' choosing the symmetric minimal spillovers ($\beta_i=\beta_j=0$) is the only pure strategy Nash equilibrium(NE). That is, it is the best response for any firm to choose minimal spillovers when the other firm under the RJV chooses minimal spillovers ($V_i(\beta_i=0,\beta_j=0)>V_i(\beta_i=1,\beta_j=0)$ for any firm $i,j=1,2$, $i\neq j$). There are two ways to affect firms' profits under the RJV. The firm under the RJV can increase their profits by sharing no information from the other firm because it yields higher price through less R&D investment and less production, compared to the game $N\overline{N}$. The other way to increase the firms' profits under the RJV is to increase

[22] There may be mixed strategy Nash equilibria, but we focus on looking only at pure strategy Nash equilibria.

market share. This is accomplished when firms under the RJV completely share their information because they have an incentive to increase R&D, which yields the increase of the final output production (for more detail, see section 4). If there were no spillover costs ($k = 0$), the firms under the RJV will always choose maximal spillovers because the market share effect dominates the price effect on the firms' profits. As long as spillover costs are sufficiently high, however, it is beneficial for the firms to choose minimal spillovers because the market share effect is overwhelmed by the negative effect of spillover costs and the price effect.

Result1: a)($\beta_i = 0, \beta_j = 0$) is NE for $k > k^1$. b) ($\beta_i = 1, \beta_j = 1$) is NE for $k < k^2$.

c) ($\beta_i = 0, \beta_j = 0$) and ($\beta_i = 1, \beta_j = 1$) are NEa for $k^1 < k < k^2$.

Proof: For $i, j = 1,2$, $i \neq j$, and $\gamma > 24/5$

a) $$V_i(1,0,k=0) - V_i(0,0) = \frac{12\gamma(A-c)^2 I(\gamma)}{(125\gamma^3 - 470\gamma^2 + 420\gamma - 96)^2 (125\gamma^2 - 210\gamma + 48)^2} \equiv k^1 > 0$$

$$I(\gamma) = 2734375\gamma^8 - 22921875\gamma^7 + 80455000\gamma^6 + 153625000\gamma^5 - 1735062\gamma^4 - 11796736\gamma^3$$
$$+ 46949376\gamma^2 - 10027008\gamma + 884736 > 0$$

b) $$V_i(1,1,k=0) - V_i(0,1) = \frac{12\gamma(A-c)^2 J(\gamma)}{(125\gamma^3 - 470\gamma^2 + 420\gamma - 96)^2 (125\gamma^2 - 480\gamma + 192)^2} \equiv k^2 > 0$$

$$J(\gamma) = 2734375\gamma^7 + 167356250\gamma^6 - 44580500\gamma^5 + 688615200\gamma^4 - 629081600\gamma^3$$
$$+ 331616256\gamma^2 - 92749824\gamma + 10616832 > 0$$

c)[23] It is a straightforward result from $k^1 < k^2$ (see corollary 1 for the numerical example)

Secondly, if spillover costs are sufficiently low ($k < k^2$), then the NE consists of both firms' choosing the symmetric maximal spillovers ($\beta_i = \beta_j = 1$) under the RJV. The intuition is that, as long as spillover costs are sufficiently low, it is more beneficial for the

[23] The comparison of the size between two critical values of spillover costs can be checked analytically using the program, such as 'Scientific Notebook'.

firm to choose maximal spillovers because the increased market share effect dominates the negative effect of spillover costs and the price effect on their profits, that is, $V_i(\beta_i=1,\beta_j=1)>V_i(\beta_i=0,\beta_j=1)$ for any firm $i,j=1,2$, $i\neq j$. Lastly, if spillover costs lie in an intermediate level ($k^1<k<k^2$), then there exist two Nash equilibria: $\beta_i=\beta_j=0$ and $\beta_i=\beta_j=1$. That is, for any firm $i,j=1,2$, $i\neq j$, $V_i(\beta_i=0,\beta_j=0)>V_i(\beta_i=1,\beta_j=0)$ and $V_i(\beta_i=1,\beta_j=1)>V_i(\beta_i=0,\beta_j=1)$). We here provide a numerical example to clarify the above results. Table 3 shows the payoff of the firm under the RJV for $\gamma=5, a-c=10$. Corollary 1 identifies the Nash equilibria for the numerical example with $\gamma=5, a-c=10$.

Table 4.4 ($V_i(\beta_i,\beta_j), V_j(\beta_i,\beta_j)$) for $\gamma=5, a-c=10$ under the game $J\overline{N}$

	$\beta_j=0$	$\beta_j=1$
$\beta_i=0$	3.4305, 3.4305	1.225, 9.1769-k
$\beta_i=1$	9.1769-k, 1.225	9.1076-k, 9.1076-k

Corollary 1: Consider a numerical example with $\gamma=5, a-c=10$ under the game $J\overline{N}$. Then,

a) ($\beta_i=0,\beta_j=0$) is NE for $k>k^1\equiv 5.7464$.

b) ($\beta_i=1,\beta_j=1$) is NE for $k<k^2\equiv 7.8826$

c) ($\beta_i=0,\beta_j=0$) and ($\beta_i=1,\beta_j=1$) are NEa for $5.7464\equiv k^1<k<k^2\equiv 7.8826$.

Proof: It is straightforward to show the result from Table 4.

4.3.2.3 R&D cooperation in each country (game $J\overline{J}$)

In this section, we consider the case where two firms in each country form an RJV to coordinate R&D activities. Thus, there exist two RJVs, one at home and the other in the foreign country. Thus, firms' unit production cost can be written by $C_i=c-\chi_i-\beta_i\chi_j$, $\overline{C}_i=c-\overline{\chi}_i-\overline{\beta}_i\overline{\chi}_j$, where $i,j=1,2$, $i\neq j$. The final stage profits for each firm are given by equation (2). The firms under the RJV in both countries maximize their joint profit while choosing the R&D investment and the amount of information sharing simultaneously. The firms incur spillover costs to absorb other firm's knowledge under the RJV. The joint profits ($V^{HT} \equiv V_i + V_j$) for the home firms can be written by

$$(12)\, V^{HT} = \frac{1}{25}\{A - c + (4-\beta_j)\chi_i + (4\beta_i - 1)\chi_j - (1+\overline{\beta}_j)\overline{\chi}_i - (1+\overline{\beta}_i)\overline{\chi}_j\}^2 - k(\beta_i + \beta_j)$$

$$+\frac{1}{25}\{A - c + (4-\beta_i)\chi_j + (4\beta_j - 1)\chi_i - (1+\overline{\beta}_j)\overline{\chi}_i - (1+\overline{\beta}_i)\overline{\chi}_j\}^2 - \frac{\gamma}{2}(\chi_i^2 + \chi_j^2)$$

where, $i, j = 1,2$, $i \neq j$.

The first order conditions of spillovers and R&D investment for the home firms are

$$(13)\ \frac{\partial V^{HT}}{\partial \beta_i} = \frac{2}{25}\{A - c + (4-\beta_j)\chi_i + (4\beta_i - 1)\chi_j - (1+\overline{\beta}_j)\overline{\chi}_i - (1+\overline{\beta}_i)\overline{\chi}_j\}(4\chi_j)$$

$$+\frac{2}{25}\{A - c + (4-\beta_i)\chi_j + (4\beta_j - 1)\chi_i - (1+\overline{\beta}_j)\overline{\chi}_i - (1+\overline{\beta}_i)\overline{\chi}_j\}(-\chi_j) - k = 0$$

$$\frac{\partial V^{HT}}{\partial \chi_i} = \frac{2}{25}\{A - c + (4-\beta_j)\chi_i + (4\beta_i - 1)\chi_j - (1+\overline{\beta}_j)\overline{\chi}_i - (1+\overline{\beta}_i)\overline{\chi}_j\}(4-\beta_j)$$

$$+\frac{2}{25}\{A - c + (4-\beta_i)\chi_j + (4\beta_j - 1)\chi_i - (1+\overline{\beta}_j)\overline{\chi}_i - (1+\overline{\beta}_i)\overline{\chi}_j\}(4\beta_j - 1) - \gamma\chi_i = 0$$

where, $i, j = 1,2$, $i \neq j$.

The second order conditions are: For $i, j = 1,2$, $i \neq j$.

$$(14)\ \frac{\partial^2 V^{HT}}{\partial \beta_i^2} = \frac{34}{25}\chi_i^2 > 0,\quad \frac{\partial^2 V^{HT}}{\partial \beta_i \beta_i} = -\frac{16}{25}\chi_i\chi_j < 0$$

$$\frac{\partial^2 V^{kT}}{\partial \chi_i^2} = \frac{2}{25}\{(4-\beta_i)^2 + (4\beta_j - 1)^2\} - \gamma < 0 \text{ for all } 0 \leq \beta \leq 1 \text{ if } \gamma > \frac{36}{25}$$

$$\frac{\partial^2 V^{HT}}{\partial \chi_i \chi_j} = \frac{2}{25}\{(4-\beta_j)(4\beta_i - 1) + (4-\beta_i)(4\beta_j - 1)\}$$

Likewise, the first and second order conditions for the foreign firms can be derived. Assuming that R&D investment and the spillovers are simultaneously determined, we can solve the problem. From the first order conditions, we can derive the following four best response functions of R&D investment.

$$(15)\ \chi_i = \frac{6(A-c)(1+\beta_j)+2BH\chi_j-6(1+\beta_j)\{(1+\overline{\beta}_j)\overline{\chi}_i+(1+\overline{\beta}_i)\overline{\chi}_j)\}}{DH},\ i,j=1,2,\ i\neq j.$$

$$DH = 25\gamma-2\{(4-\beta_j)^2+(4\beta_j-1)^2\},\ BH=\{(4\beta_i-1)(4-\beta_j)+(4\beta_j-1)(4-\beta_i)\}$$

$$\overline{\chi}_i = \frac{6(A-c)(1+\overline{\beta}_j)+2BF\overline{\chi}_j-6(1+\overline{\beta}_j)\{(1+\beta_j)\chi_i+(1+\beta_i)\chi_j)\}}{DF},\ i,j=1,2,\ i\neq j.$$

$$DF = 25\gamma-2\{(4-\overline{\beta}_j)^2+(4\overline{\beta}_j-1)^2\},\ BF=\{(4\overline{\beta}_i-1)(4-\overline{\beta}_j)+(4\overline{\beta}_j-1)(4-\overline{\beta}_i)\}$$

Table 4.5 The possible outcomes of spillover choice under the game $J\overline{J}$

1. All four firms choose minimal spillovers, e.g., $\beta_i=\beta_j=\overline{\beta}_i=\overline{\beta}_j=0$
2. One firm chooses maximal spillovers while the other three firms choose minimal spillovers, e.g., $\beta_i=1, \beta_j=\overline{\beta}_i=\overline{\beta}_j=0$
3. Both firms in one country choose maximal spillovers while both firms in the other country choose minimal spillovers, e.g., $\beta_i=\beta_j=1, \overline{\beta}_i=\overline{\beta}_j=0$
4. One firm in each country chooses maximal spillovers while the other firm in each country chooses minimal spillovers, e.g., $\beta_i=1, \beta_j=0, \overline{\beta}_i=1, \overline{\beta}_j=0$
5. Three firms choose maximal spillovers while the remaining firm chooses minimal spillovers, e.g., $\beta_i=\beta_j=\overline{\beta}_i=1, \overline{\beta}_j=0$
6. All four firms choose maximal spillovers, e.g., $\beta_i=\beta_j=\overline{\beta}_i=\overline{\beta}_j=1$

From the second order condition, we consider corner solutions with respect to spillovers (for the home firms $\beta=0$ or $\beta=1$, for the foreign firms $\overline{\beta}=0$ or $\overline{\beta}=1$), which is basically due to the assumption of the linear spillover costs. Since all four firms can choose two strategies (minimal or maximal spillovers), the total number of possible outcomes is sixteen. By the symmetry, it is enough to consider the six cases in Table 5.

We derive the NEa in firms' decision of spillovers and illustrate the results further, based on the numerical example with $\gamma = 5, A - c = 10$. The payoff for each firm is described in table 6. The first outcome ($\beta_i = \beta_j = \overline{\beta}_i = \overline{\beta}_j = 0$) is the NE if $k > k^{13} \equiv 6.0384$ because nobody has an incentive to deviate (e.g., $V_i(0,0,0,0) > V_i(1,0,0,0)$ for $k > k^{13}$). The outcome ($\beta_i = 1, \beta_j = \overline{\beta}_i = \overline{\beta}_j = 0$) is never a NE because at least one firm has an incentive to deviate. For example, the home firm *i* doesn't deviate if $k < k^{13} \equiv 6.0384$, home firm *j* doesn't deviate if $k > k^{14} \equiv 7.9028$, and foreign firm *i* (or *j*) doesn't deviate if $k < 3.9323$. But no value of k exists such that all three cases are satisfied. The outcome ($\beta_i = \beta_j = 1, \overline{\beta}_i = \overline{\beta}_j = 0$) is the NE if $0.20048 \equiv k^{11} < k < k^{14} \equiv 7.9028$ because nobody has an incentive to deviate (if $k^{11} < k < k^{14}$, $V_j(1,1,0,0) > V_j(1,0,0,0)$ and $\overline{V}_i(1,1,0,0) > \overline{V}_i(1,1,1,0)$).

Table 4.6 Payoff in firms' choice of spillovers under the game $J\overline{J}$ for $\gamma = 5, A - c = 10$

$(\beta_i, \beta_j, \overline{\beta}_i, \overline{\beta}_j)$	V_i	V_j	$\overline{V}_i$	$\overline{V}_j$
(0,0,0,0)	3.778	3.778	3.778	3.778
(1,0,0,0)	9.8164-k	1.3103	1.8147	1.8147
(1,1,0,0)	9.2131-k	9.2131-k	0.0515	0.0515
(1,0,1,0)	5.747-k	0.76714	5.747-k	0.76714
(1,1,1,0)	8.3292-k	8.3292-k	0.25198-k	0.03364
(1,1,1,1)	2.5978-k	2.5978-k	2.5978-k	2.5978-k

The outcome ($\beta_i = 1, \beta_j = 0, \overline{\beta}_i = 1, \overline{\beta}_j = 0$) is never a NE because at least one firm has an incentive to deviate. For example, the home firm j doesn't deviate if $k > 7.56206$, and foreign firm *i* doesn't deviate if $k < 3.9323$, but the value of k doesn't exist such that all two cases are satisfied. The outcome ($\beta_i = \beta_j = \overline{\beta}_i = 1, \overline{\beta}_j = 0$) is not a NE because at least one firm has an incentive to deviate. For example, the home firm *j* doesn't deviate if $k < 7.56206$, foreign firm i doesn't deviate if $k < k^{11} \equiv 0.20048$, and foreign firm j doesn't deviate if $k > k^{12} \equiv 2.56416$. But no value of k exists such that all three cases are satisfied. The outcome ($\beta_i = \beta_j = \overline{\beta}_i = \overline{\beta}_j = 1$) is a NE if $k < k^{12} \equiv 2.56416$ because nobody has an incentive to deviate (e.g., for $k < k^{12}$, $\overline{V}_j(1,1,1,1) > \overline{V}_j(1,1,1,0)$). Table 7 provides the definition and numerical value of critical value of spillover costs, and corollary 2 summarizes the above results.

Table 4.7 Definition (and numerical value) of critical value of spillover costs[24]

$k^{14} \equiv V_i(1,1,0,0;k=0) - V_i(0,1,0,0) \equiv V_j(1,1,0,0;k=0) - V_i(1,0,0,0)$ $\equiv \overline{V}_i(0,0,1,1;k=0) - \overline{V}_i(0,0,0,1) \equiv \overline{V}_j(0,0,1,1;k=0) - \overline{V}_j(0,0,1,0) \equiv 7.9028$
$k^{13} \equiv V_i(1,0,0,0;k=0) - V_i(0,0,0,0) \equiv V_j(0,1,0,0;k=0) - V_i(0,0,0,0)$ $\equiv \overline{V}_i(0,0,1,0;k=0) - \overline{V}_i(0,0,0,0) \equiv \overline{V}_j(0,0,0,1;k=0) - \overline{V}_j(0,0,0,0) \equiv 6.0384$
$k^{12} \equiv V_i(1,1,1,1;k=0) - V_i(0,1,1,1) \equiv V_j(1,1,1,1;k=0) - V_i(1,0,1,1)$ $\equiv \overline{V}_i(1,1,1,1;k=0) - \overline{V}_i(1,1,0,1) \equiv \overline{V}_j(1,1,1,1;k=0) - \overline{V}_j(1,11,,0) \equiv 2.56416$
$k^{11} \equiv V_i(1,0,1,1;k=0) - V_i(0,0,1,1) \equiv V_j(0,1,1,1;k=0) - V_i(0,0,1,1)$ $\equiv \overline{V}_i(1,1,1,0;k=0) - \overline{V}_i(1,1,0,0) \equiv \overline{V}_j(1,1,0,1;k=0) - \overline{V}_j(1,10,0) \equiv 0.20048$
$k^{11} < k^{12} < k^{13} < k^{14}$

Corollary 2: Consider a numerical example with $\gamma = 5, a - c = 10$ under the game $J\overline{J}$. Then a) if $k > k^{14}$, the NE $(\beta_i, \beta_j, \overline{\beta}_i, \overline{\beta}_j)$ is (0,0,0,0). b) if $k^{12} < k < k^{14}$, the NEa are (0,0,0,0), (1,1,0,0), or (0,0,1,1). c) if $k^{11} < k < k^{12}$, NEa are (1,1,1,1), (1,1,0,0), or (0,0,1,1). d) if $k < k^{11}$, the NE is (1,1,1,1).

Proof: See Table 6 and above explanation.

[24] We can derive the Nash equilibria analytically. The comparison between the firms' profits is very complex, and the calculations for each critical value of spillover costs are very tedious. The program, such as 'Scientific Notebook', may be helpful to check the results.

The final outcomes for each NE are as follows:

Case 1: firms under the RJV in both countries choose minimal spillovers ($\beta = \overline{\beta} = 0$)

$$\chi^{J\bar{J}}(\beta^{J\bar{J}} = \overline{\beta}^{J\bar{J}} = 0) = \frac{6(A-c)}{25\gamma-6} = \overline{\chi}^{J\bar{J}}(\beta^{J\bar{J}} = \overline{\beta}^{J\bar{J}} = 0)$$

$$q^{J\bar{J}}(\beta^{J\bar{J}} = \overline{\beta}^{J\bar{J}} = 0) = \frac{5\gamma(A-c)}{25\gamma-6} = \overline{q}^{J\bar{J}}(\beta^{J\bar{J}} = \overline{\beta}^{J\bar{J}} = 0),\ Q^{J\bar{J}}(\beta^{J\bar{J}} = \beta^{J\bar{J}} = 0) = \frac{20\gamma(A-c)}{25\gamma-6}$$

$$V^{J\bar{J}}(\beta^{J\bar{J}} = \overline{\beta}^{J\bar{J}} = 0) = \frac{\gamma(A-c)^2(25\gamma-18)}{(25\gamma-6)^2} = \overline{V}^{J\bar{J}}(\beta^{J\bar{J}} = \overline{\beta}^{J\bar{J}} = 0)$$

Case 2: firms under the RJV in both countries choose maximal spillovers ($\beta = \overline{\beta} = 1$)

$$\chi^{J\bar{J}}(\beta^{J\bar{J}} = \overline{\beta}^{J\bar{J}} = 1) = \frac{12(A-c)}{25\gamma-24} = \overline{\chi}^{J\bar{J}}(\beta^{J\bar{J}} = \overline{\beta}^{J\bar{J}} = 1)$$

$$q^{J\bar{J}}(\beta^{J\bar{J}} = \overline{\beta}^{J\bar{J}} = 1) = \frac{5\gamma(A-c)}{25\gamma-24} = \overline{q}^{J\bar{J}}(\beta^{J\bar{J}} = \overline{\beta}^{J\bar{J}} = 1),\ Q^{J\bar{J}}(\beta^{J\bar{J}} = \beta^{J\bar{J}} = 1) = \frac{20\gamma(A-c)}{25\gamma-24}$$

$$V^{J\bar{J}}(\beta^{J\bar{J}} = \overline{\beta}^{J\bar{J}} = 1) = \frac{\gamma(A-c)^2(25\gamma-72)}{(25\gamma-24)^2} - k = V^{J\bar{J}}(\beta^{J\bar{J}} = \overline{\beta}^{J\bar{J}} = 1)$$

Case 3: firms under the RJV choose different spillovers between two countries. ($\beta \neq \overline{\beta}(e.g., \beta = 0, \overline{\beta} = 1)$).

$$\chi^{J\bar{J}}(\beta^{J\bar{J}} = 0, \overline{\beta}^{J\bar{J}} = 1) = \frac{6(A-c)(5\gamma-24)}{125\gamma^2-450\gamma+144},\ \overline{\chi}^{J\bar{J}}(\beta^{J\bar{J}} = 0, \overline{\beta}^{J\bar{J}} = 1) = \frac{12(A-c)(5\gamma-6)}{125\gamma^2-450\gamma+144}$$

$$q^{J\bar{J}}(\beta^{J\bar{J}} = 0, \overline{\beta}^{J\bar{J}} = 1) = \frac{5\gamma(A-c)(5\gamma-24)}{125\gamma^2-450\gamma+144},\ \overline{q}^{J\bar{J}}(\beta^{J\bar{J}} = 0, \overline{\beta}^{J\bar{J}} = 1) = \frac{5\gamma(A-c)(5\gamma-6)}{125\gamma^2-450\gamma+144}$$

$$V^{J\bar{J}}(\beta^{J\bar{J}} = 0, \overline{\beta}^{J\bar{J}} = 1) = \frac{\gamma(A-c)^2(5\gamma-24)^2(25\gamma-18)}{(125\gamma^2-450\gamma+144)^2}$$

$$\overline{V}^{J\bar{J}}(\beta^{J\bar{J}} = 0, \overline{\beta}^{J\bar{J}} = 1) = \frac{\gamma(A-c)^2(5\gamma-6)^2(25\gamma-72)}{(125\gamma^2-450\gamma+144)^2} - k$$

$$Q^{J\bar{J}}(\beta^{J\bar{J}} = 0, \overline{\beta}^{J\bar{J}} = 1) = \frac{10\gamma(A-c)(10\gamma-30)}{125\gamma^2-450\gamma+144}$$

4.4 The outcome comparison

The central contribution of the R&D literature dealing with spillovers is to provide a performance comparison between R&D cooperation and non-cooperation, among firms that remain competitors in the product market (see d'Aspremont and Jacquemin (1988) and Kamien et al. (1992)). In this section, we examine under which case firms invest more in R&D and produce more final output. Aggregate outcomes are compared as well as individual outcomes. Aggregate R&D investment and final output are denoted by X and Q, respectively. We firstly compare aggregate outcomes between the game $N\bar{N}$ and $J\bar{N}$, and then we compare outcomes under the game $J\bar{J}$ with those under the game $N\bar{N}$ and $J\bar{N}$.

Result 2: a) $\chi^{J\bar{N}}(\beta^{J\bar{N}}=1) > \bar{\chi}^{J\bar{N}}(\beta^{J\bar{N}}=0) > \chi^{N\bar{N}} = \bar{\chi}^{N\bar{N}} > \bar{\chi}^{J\bar{N}}(\beta^{J\bar{N}}=1) > \chi^{J\bar{N}}(\beta^{J\bar{N}}=0)$

b) $X^{J\bar{N}}(\beta^{J\bar{N}}=1) > X^{N\bar{N}} > X^{J\bar{N}}(\beta^{J\bar{N}}=0)$

where $X^{N\bar{N}} = 2(\chi^{N\bar{N}} + \bar{\chi}^{N\bar{N}})$, $X^{J\bar{N}} = 2(\chi^{J\bar{N}} + \chi^{J\bar{N}})$

c) $q^{J\bar{N}}(\beta^{J\bar{N}}=1) > \bar{q}^{J\bar{N}}(\beta^{J\bar{N}}=0) > q^{N\bar{N}} = \bar{q}^{N\bar{N}} > \bar{q}^{J\bar{N}}(\beta^{J\bar{N}}=1) > q^{J\bar{N}}(\beta^{J\bar{N}}=0)$

d) $Q^{J\bar{N}}(\beta^{J\bar{N}}=1) > Q^{N\bar{N}} > Q^{J\bar{N}}(\beta^{J\bar{N}}=0) \Leftrightarrow P^{J\bar{N}}(\beta^{J\bar{N}}=1) > P^{N\bar{N}} > P^{J\bar{N}}(\beta^{J\bar{N}}=0)$

Cooperative R&D efforts are greater (less) than non-cooperative efforts if firms within an RJV achieve complete (no) information sharing, that is, $\chi^{J\bar{N}}(\beta^{J\bar{N}}=1) > \chi^{N\bar{N}} > \chi^{J\bar{N}}(\beta^{J\bar{N}}=0)$. This result holds if firms within an RJV can share more (less) than half the information from each other, that is, $\beta > 1/2$.[23] Note that in our model partial spillovers ($0 < \beta < 1$) cannot be the firms' optimal choice on information sharing under the RJV, which is due to the assumption of linear spillover costs. The result is usually explained in terms of the 'free-rider' effect in the R&D literature where they focus on

[23] A similar result has been shown in previous studies where they focus on examining the role of involuntary spillovers in comparing R&D efforts between R&D non-cooperation and cooperation case (see d'Aspremont and Jacquemin (1988) and Kamien et al. (1992)).

examining the role of involuntary exogenous spillovers.

However, our results should be interpreted differently since we do not assume the existence of involuntary spillovers but consider complete endogeniety of spillovers under the RJV. First of all, we need to provide intuition as to why firms within an RJV share complete or no information. There are two ways to affect joint profits of the RJV. Firstly, firms under the RJV may try to increase the final market price by reducing R&D investment. This happens when firms within an RJV choose no information sharing, which decreases R&D investment (thus decreasing final output production), when compared to the R&D non-cooperation. Secondly, firms under the RJV may target market share to increase their joint profits. One way to do that is to reduce unit production costs by increasing R&D investment, and this is accomplished when firms under the RJV achieve complete information sharing. Which way is more desirable to increase joint profits? It totally depends on spillover costs. When spillover costs are sufficiently high there is no reason why firms should incur sufficient spillover costs. Therefore, they choose to increase market price by sharing no information. However, when spillover costs are very low it is more profitable to increase R&D investment (thus final output and market share) by completely sharing information within an RJV.

The result becomes reversed for non-cooperating firms. When cooperating firms (through forming an RJV) choose maximal spillovers non-cooperating firms invest less in R&D ($\overline{\chi}^{N\bar{N}} > \overline{\chi}^{J\bar{N}}(\beta^{J\bar{N}} = 1)$), when compared to the R&D non-cooperation game, while they invest more when cooperating firms share no information within an RJV ($\overline{\chi}^{J\bar{N}}(\beta^{J\bar{N}} = 0) > \overline{\chi}^{N\bar{N}}$). Note that R&D effort is a strategic substitute between the cooperating and non-cooperating firms.[24] This is confirmed by the fact that the slope of the reaction function is negative (see equation (10)). Cooperating firms have an incentive to increase R&D efforts when they completely share information within an RJV. This is because it gives them a cost advantage against non-cooperating firms who are competitors in a final market. Meanwhile, the non-cooperating firms' incentive to do R&D decreases as

[24] That is, the marginal profit of cooperating firms' R&D decreases as non-cooperating firms' R&D increases. Technically, $\partial V^2 / \partial \chi^{J\bar{N}} \partial \overline{\chi}^{J\bar{N}} < 0$. For more detail, see Burlow et al. (1985).

cooperating firms increase R&D level since their marginal profit of own R&D decreases. Next, when cooperating firms do not share any information within an RJV they decrease R&D efforts compared to R&D non-cooperation ($\chi^{N\bar{N}} > \chi^{J\bar{N}}(\beta^{J\bar{N}} = 0)$). This is because by doing so they can make gains through increasing final market price. Then, by the nature of strategic substitutes it should be obvious that non-cooperating firms have an incentive to increase R&D efforts ($\bar{\chi}^{J\bar{N}}(\beta^{J\bar{N}} = 0) > \bar{\chi}^{N\bar{N}}$ and $\bar{q}^{J\bar{N}}(\beta^{J\bar{N}} = 0) > \bar{q}^{N\bar{N}}$). In this case, it is interesting to see that per firm profit for non-cooperating firms exceeds the cooperating firm's profit ($\bar{V}^{J\bar{N}}(\beta^{J\bar{N}} = 0) > V^{J\bar{N}}(\beta^{J\bar{N}} = 0) > V^{N\bar{N}} = \bar{V}^{N\bar{N}}$). This result may be compared to merger's loss (Salant et al. 1983). In Salant et al. merged firms reduce their outputs to increase market price in the industry. However, merged firms lose, when compared to the equilibrium under the non-cooperation game, because firms outside of the merger expand their outputs. In our model, unlike the result of a merger's loss, cooperating firms (under the RJV) always make gains regardless of non-cooperating firms' reactions. Meanwhile, non-cooperating firms benefit only if cooperating firms do not share any information within an RJV.

Aggregate R&D efforts under the game $J\bar{N}$ are greater (less) than under the game $N\bar{N}$ only if firms within an RJV achieve complete (no) information sharing, that is, $X^{J\bar{N}}(\beta^{J\bar{N}} = 1) > X^{N\bar{N}} > X^{J\bar{N}}(\beta^{J\bar{N}} = 0)$. Recall that under the game $J\bar{N}$ cooperating firms' R&D efforts increase (decrease) while non-cooperating firms' R&D levels decrease (increase), when compared to R&D level under the game $N\bar{N}$, if firms within an RJV choose maximal (minimal) spillovers. However, the cooperating firms' decision on R&D efforts is crucial for this comparison in the sense that it always dominates the non-cooperating firms' decision, that is, $\left|\chi^{J\bar{N}} - \chi^{N\bar{N}}\right| > \left|\bar{\chi}^{J\bar{N}} - \bar{\chi}^{N\bar{N}}\right|$. This implies that the spillover choice under the RJV plays a key role in determining aggregate R&D levels. Thus, if it is difficult for firms to share information within an RJV (spillover costs are sufficiently high) then an RJV formation consisting of two firms yields less aggregate R&D efforts than under the R&D non-cooperation.

Next, we compare outcomes under the game $J\overline{J}$ with those under the game $N\overline{N}$ and $J\overline{N}$. As explained in the outcome comparison between the game $N\overline{N}$ and $J\overline{N}$, there are two main effects of the R&D cooperation through forming an RJV on R&D levels: Competitive and anticompetitive effect. If spillover costs are very low then RJV formation in each country stimulates R&D competition between two countries. Firms within an RJV in each country have an incentive to increase R&D efforts by completely sharing information, when compared to both the game $N\overline{N}$ and $J\overline{N}$, because it reduces unit production costs, thus increasing market share. This yields higher R&D levels under the game $J\overline{J}$ than under both the game $N\overline{N}$ and game $J\overline{N}$ $(\chi^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=1)>\chi^{J\overline{N}}(\beta^{J\overline{N}}=1)>\chi^{N\overline{N}})$. It is straightforward to show that aggregate R&D efforts and final output (market price) are the highest (least) under game $J\overline{J}$ $(X^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=1)>X^{J\overline{N}}(\beta^{J\overline{N}}=1)>X^{N\overline{N}}$, $Q^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=1)>Q^{J\overline{N}}(\beta^{J\overline{N}}=1)>Q^{N\overline{N}})$.

Result 3:

a) $\chi^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=1)>\chi^{J\overline{N}}(\beta^{J\overline{N}}=1)>\chi^{N\overline{N}}>\chi^{J\overline{N}}(\beta^{J\overline{N}}=0)>\chi^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=0)$

b) $X^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=1)>X^{J\overline{N}}(\beta^{J\overline{N}}=1)>X^{N\overline{N}}>X^{J\overline{N}}(\beta^{J\overline{N}}=0)>X^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=0)$

where, $X^{J\overline{J}}\equiv 2(\chi^{J\overline{J}}+\overline{\chi}^{J\overline{J}})=4\chi^{J\overline{J}}$.

c) $q^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=1)>q^{J\overline{N}}(\beta^{J\overline{N}}=1)>q^{N\overline{N}}>q^{J\overline{N}}(\beta^{J\overline{N}}=0)>q^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=0)$

d) $Q^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=1)>Q^{J\overline{N}}(\beta^{J\overline{N}}=1)>Q^{N\overline{N}}>Q^{J\overline{N}}(\beta^{J\overline{N}}=0)>Q^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=0)$

$\Leftrightarrow P^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=1)<P^{J\overline{N}}(\beta^{J\overline{N}}=1)<P^{N\overline{N}}<P^{J\overline{N}}(\beta^{J\overline{N}}=0)<P^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=0)$

Meanwhile, the anticompetitive effect dominates if spillover costs are sufficiently high. As long as firms should incur high costs or face difficulties to share information within an RJV, they have an incentive to reduce R&D levels by sharing no information $(\chi^{N\overline{N}}>\chi^{J\overline{N}}(\beta^{J\overline{N}}=0)>\chi^{J\overline{J}}(\beta^{J\overline{J}}=\overline{\beta}^{J\overline{J}}=0))$. This yields the lowest (highest) aggregate

R&D levels and final output (market price) when firms within an RJV in each country choose minimal spillovers. Note that symmetric minimal spillovers $(\beta^{J\bar{J}} = \overline{\beta}^{J\bar{J}} = 0)$ are chosen under the game $J\overline{J}$ as long as spillover costs are sufficiently high ($k > k^2$) regardless of whether we allow symmetry or asymmetry on information sharing between two countries.

From the above results, we may conclude that allowing two RJVs in the industry (game $J\overline{J}$) brings about more competitive (anticompetitive) outcomes than allowing one RJV consisting of some firms in the industry (game $J\overline{N}$) or rejecting RJV formation (game $N\overline{N}$) if spillover costs are sufficiently low (high). Thus, antitrust authorities should consider allowing RJV formation as much as possible for the industry with low spillover costs (or difficulties). Meanwhile, it may be more desirable that no RJV formation should be allowed for the industry with high spillover costs.

4.5 Welfare implications

In this section, we examine the welfare effects of the RJV and its policy implications. We consider two market structures: a "third-market" and an integrated market structure. The reason we add an integrated market, unlike Brander and Spencer (1983, 1985), is because there can be a negative effect of the RJV on consumer surplus. The objective of the government is to maximize domestic welfare. W and $\overline{W}$ denote the welfare of the home and foreign country, respectively. Throughout section 3, we have derived the Nash Equilibria (NEa) of spillovers and R&D efforts (R&D stage). Focusing on these NEa, we investigate the welfare implications of the RJV. In each market structure, we ask two questions. First, given that the foreign country does not allow an RJV formation, when does the home country have an incentive to allow its domestic firms to form an RJV? Second, when do both countries have an incentive to allow an RJV formation in each country? To answer the second question, we identify the NE(a) of the policy game where both the home and the foreign countries simultaneously decide whether to allow an RJV or not, and provide the welfare implications for each NE of the policy game. Note that we take advantage of the game $N\overline{N}$ as the benchmark.

4.5.1 A "third-market" structure

First, we consider a "third-market" in which all four firms compete with a homogenous good. The domestic welfare is equal to the sum of firm's profits ($W = \sum_i V_i, \overline{W} = \sum_i \overline{V}_i \ \ i = 1,2$).

4.5.1.1 When only the home country allows an RJV formation

Whether the home country can make welfare improvement by allowing an RJV formation, given that the foreign country does not, depends on both spillover costs and the degree of information sharing that the home firms choose under the RJV. Recall that we have two kinds of Nash Equilibria ($\beta_i = \beta_j = 0$, or $\beta_i = \beta_j = 1$) in three domains of spillover costs ($k > k^2$, $k^1 < k < k^2$, $k < k^1$). First, suppose that spillover costs are sufficiently high ($k > k^2$). Then, the home firms under the RJV choose symmetric minimal spillovers. The domestic welfare of the home country is higher under this outcome, when compared to the game $N\overline{N}$ ($W^{J\overline{N}}(\beta_i = \beta_j = 0) - W^{N\overline{N}} > 0$). Thus, the government intervention may be unnecessary except for allowing an RJV formation. The benefits to the home country (firms) come from the fact that the home firms under the RJV do not share any information and they decrease cooperative R&D efforts. This is true, even though it sounds strange, because the home firms can increase final market price and thus their profits by doing so.

Second, suppose that spillover costs lie in an intermediate level ($k^1 < k < k^2$). Then, the home firms under the RJV choose symmetric minimal or maximal spillovers. If symmetric minimal spillovers under the RJV are guaranteed, then allowing an RJV formation benefits the home country. The same logic as the first case applies. However, if the home firms under the RJV choose maximal spillovers, then the home country is hurt in terms of the welfare, compared to the game $N\overline{N}$. As mentioned earlier, the firms can increase their profits by increasing market share, through complete information sharing within an RJV. But, for this range of spillover costs, the negative effects of spillover costs dominate the increased market share effect on the firms' profits. The policy implication is, ironically, the home government should not permit an RJV formation if the firms try to increase market share by completely sharing information within an RJV ($W^{J\overline{N}}(\beta_i = \beta_i = 1) - W^{N\overline{N}} < 0$).

Lastly, suppose that spillover costs are sufficiently low ($k < k^1$). Then, there exists another critical value of spillover costs ($k^0 < k^1$ where $k^0 \equiv V^{J\overline{N}}(1,1;k=0) - V^{N\overline{N}}$), which determines whether allowing an RJV formation is beneficial for the home country. Note that the home firms under the RJV choose symmetric maximal spillovers for this range of spillover costs. If $k^0 < k < k^1$, then the negative effects of spillover costs on the firms' profits (thus welfare) are still dominant. Therefore, it is not desirable for the government to allow an RJV formation. However, if $k < k^0$, allowing an RJV formation benefits the home country because the firms' profits increase, which is due to the increased market share, compared to the game $N\overline{N}$ ($W^{J\overline{N}}(\beta_i = \beta_i = 1) - W^{N\overline{N}} > 0$).

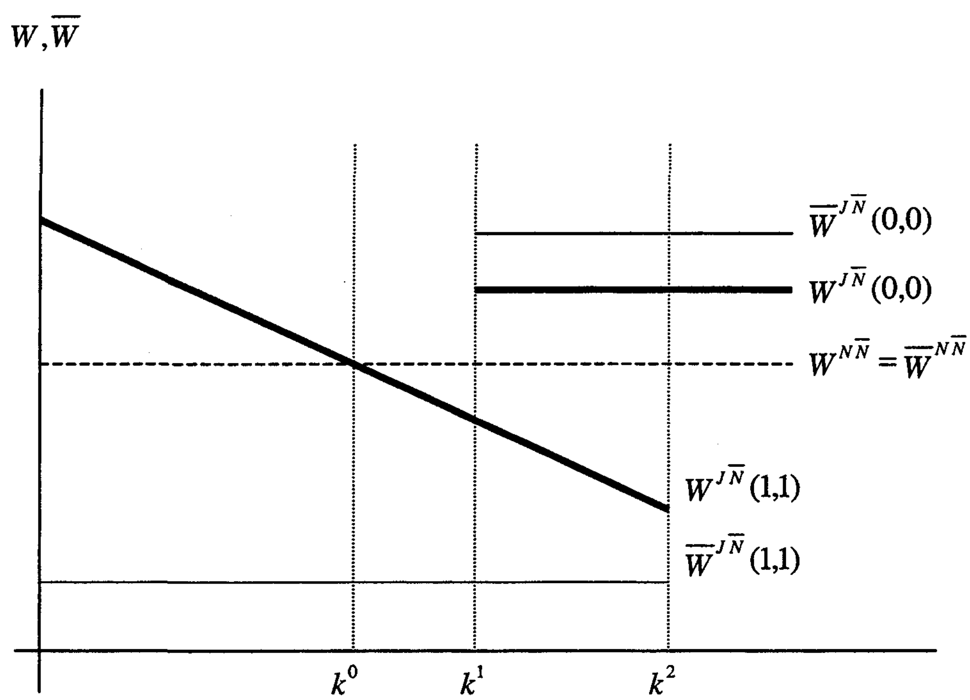

Figure 4.1 The welfare in a third market structure under the game $J\overline{N}$

Lemma 1: Suppose that the final products are produced for export to a 'third market'. Then, a) for $k > k^2$, the home country is better off by allowing an RJV formation. b) for $k^1 < k < k^2$, it is desirable for the home government to allow its domestic firms to form an

RJV only if the choice of symmetric minimal spillovers under the RJV is guaranteed. c) for $k < k^1$, there exists another critical value of spillover costs $k^0 < k^1$, which determines whether allowing an RJV formation is beneficial for the home country

Proof: a) $W^{J\bar{N}}(\beta_i = \beta_j = 0) - W^{N\bar{N}} = \dfrac{20(A-c)^2\gamma^2\{3125\gamma^3 - 16250\gamma^2 + 20640\gamma - 4746\}}{\{125\gamma^2 - 210\gamma + 48\}^2(25\gamma - 8)^2} > 0$

b)[25], c) $W^{J\bar{N}}(\beta_i = \beta_j = 1, k = 0) - W^{N\bar{N}} = \dfrac{16\gamma(A-c)^2 f_0(\gamma)}{\{125\gamma^2 - 480\gamma + 192\}^2(25\gamma - 8)^2} \equiv 2k^0 < 2k^1$

$$f_0(\gamma) \equiv 109375\gamma^4 - 580000\gamma^3 + 931200\gamma^2 - 563200\gamma + 110592$$

Whether the welfare of the foreign country increases with the home firms' RJV formation depends on the degree of information sharing that the home firms choose under the RJV. As seen in Figure 1, the foreign country is always hurt when the home firms achieve complete information sharing within an RJV while it is benefited if the home firms choose minimal spillovers. The home firms, by completely sharing information under the RJV, have an incentive to invest more in R&D and produce more final outputs ($\chi^{N\bar{N}} < \chi^{J\bar{N}}(\beta^{J\bar{N}} = 1), q^{N\bar{N}} < q^{J\bar{N}}(\beta^{J\bar{N}} = 1)$), which contracts foreign firms' production ($\bar{\chi}^{N\bar{N}} > \bar{\chi}^{J\bar{N}}(\beta^{J\bar{N}} = 1), \bar{q}^{N\bar{N}} > \bar{q}^{J\bar{N}}(\beta^{J\bar{N}} = 1)$). It decreases the foreign firms' profits and thus its welfare. This may relate to the usual 'profit-shifting' result in the strategic trade policy literature.

However, the foreign firms' profits increase if the firms in the home country choose minimal spillovers under the RJV. In this case, more surprisingly, the foreign firms' profit exceeds the home firms' profit. When the home firms choose minimal spillovers, they do so to increase price in a final market by investing less in R&D and producing less final output ($\chi^{N\bar{N}} > \chi^{J\bar{N}}(\beta^{J\bar{N}} = 0), q^{N\bar{N}} > q^{J\bar{N}}(\beta^{J\bar{N}} = 0)$, and $p^{N\bar{N}} < p^{J\bar{N}}(\beta^{J\bar{N}} = 0)$). This benefits the foreign firms whose R&D investment and final production increase, when compared to the

[25] See the appendix for the critical values of spillover costs. The comparison of the size of critical values can be easily obtained using the program, such as 'Scientific Notebook'.

R&D non-cooperation game ($\overline{\chi}^{N\bar{N}} < \overline{\chi}^{J\bar{N}}(\beta^{J\bar{N}} = 0), \overline{q}^{N\bar{N}} < \overline{q}^{J\bar{N}}(\beta^{J\bar{N}} = 0)$).[26]

Lemma 2: Consider the third market structure. Suppose that the home country allows an RJV formation. Then, a) the foreign country is better (worse) off whenever the home firms choose minimal (maximal) spillovers under the RJV. b) the welfare of the foreign country exceeds the home country's welfare when the home firms choose minimal spillovers.

Proof: a) $\overline{W}^{J\bar{N}}(\beta_i = \beta_j = 0) - \overline{W}^{N\bar{N}} = \dfrac{80(A-c)^2(25\gamma - 32)\{125\gamma^2 - 200\gamma + 48\}}{\{125\gamma^2 - 210\gamma + 48\}^2(25\gamma - 8)^2} > 0$

$$\overline{W}^{J\bar{N}}(\beta_i = \beta_j = 1) - \overline{W}^{N\bar{N}} = \frac{-640(A-c)^2(25\gamma - 32)\{125\gamma^2 - 560\gamma + 192\}}{\{125\gamma^2 - 480\gamma + 192\}^2(25\gamma - 8)^2} < 0$$

b) $\overline{W}^{J\bar{N}}(\beta_i = \beta_j = 0) - W^{J\bar{N}}(\beta_i = \beta_j = 0) = \dfrac{20(A-c)^2\gamma^2(15\gamma - 22)}{\{125\gamma^2 - 210\gamma + 48\}^2} > 0$

4.5.1.2 When both countries have an incentive to allow an RJV

In this sub-section, we provide the welfare implications when both the home and the foreign countries allow an RJV formation in each country while identifying NE(a) of the policy game where both the home and the foreign countries simultaneously decide whether to allow an RJV or not. As seen in Figure 2, there are many cases to consider. It looks complex to find NE(a) because there exist multiple NEa of spillovers both in game $J\bar{N}$ (or $N\bar{J}$) and game $J\bar{J}$, and the welfare under each NE depends on several critical values of spillover costs. Given NE of spillovers and spillover costs, however, it is straightforward to find NE(a) of the policy game.[27]

Suppose spillover costs are very low ($k < k^{11}$). Then, NE of the policy game is (Home: Allow RJV, Foreign: Allow RJV; hereafter RJV, RJV). The policy game leads to a prisoner's dilemma result since both countries are worse off ($W^{J\bar{J}}(1,1,\bar{1},\bar{1}) < W^{N\bar{N}}$,

[26] This result may be compared to merger's loss in Salant et al. (1983) as we have briefly explained in section 4.

[27] See the appendix for the numerical example with $\gamma = 5$ and $A - c = 10$.

$\overline{W}^{J\bar{J}}(1,1,\bar{1},\bar{1}) < \overline{W}^{N\bar{N}}$), when compared to the game $N\bar{N}$, but each has a unilateral incentive to allow an RJV formation ($W^{J\bar{N}}(1,1) = \overline{W}^{N\bar{J}}(\bar{1},\bar{1}) > W^{N\bar{N}} = \overline{W}^{N\bar{N}} > W^{N\bar{J}}(\bar{1},\bar{1}) = W^{N\bar{J}}(1,1)$). The intuition is, as long as spillover costs are sufficiently low, the firms under the RJV in any country try to increase market share by completely sharing information ($\beta = \overline{\beta} = 1$), which reduces firm's unit production cost, thus increases final outputs. However, the excessive R&D competition between the two countries (RJVs) results in the decrease of final market price, when compared to the R&D non-cooperation game ($P^{J\bar{J}}(\beta = \overline{\beta} = 1) < P^{N\bar{N}}$), which negatively affects firms' profits. Finally, the negative effects of spillover costs and the decreased price dominate the increased market share. This result also holds for $k^{11} < k < k^{*}$ (where k^{*} $W^{J\bar{J}}(1,1,\bar{1},\bar{1};k = k^{*}) - W^{N\bar{J}}(\bar{1},\bar{1}) = 0$ or $\overline{W}^{J\bar{J}}(1,1,\bar{1},\bar{1};k = k^{*}) - \overline{W}^{J\bar{N}}(1,1) = 0$) if the NE of spillovers ($\beta_i, \beta_j, \overline{\beta}_i, \overline{\beta}_j$) under the game $J\bar{J}$ is $(1,1,\bar{1},\bar{1})$ (For numerical example, see Table A1 in Appendix).

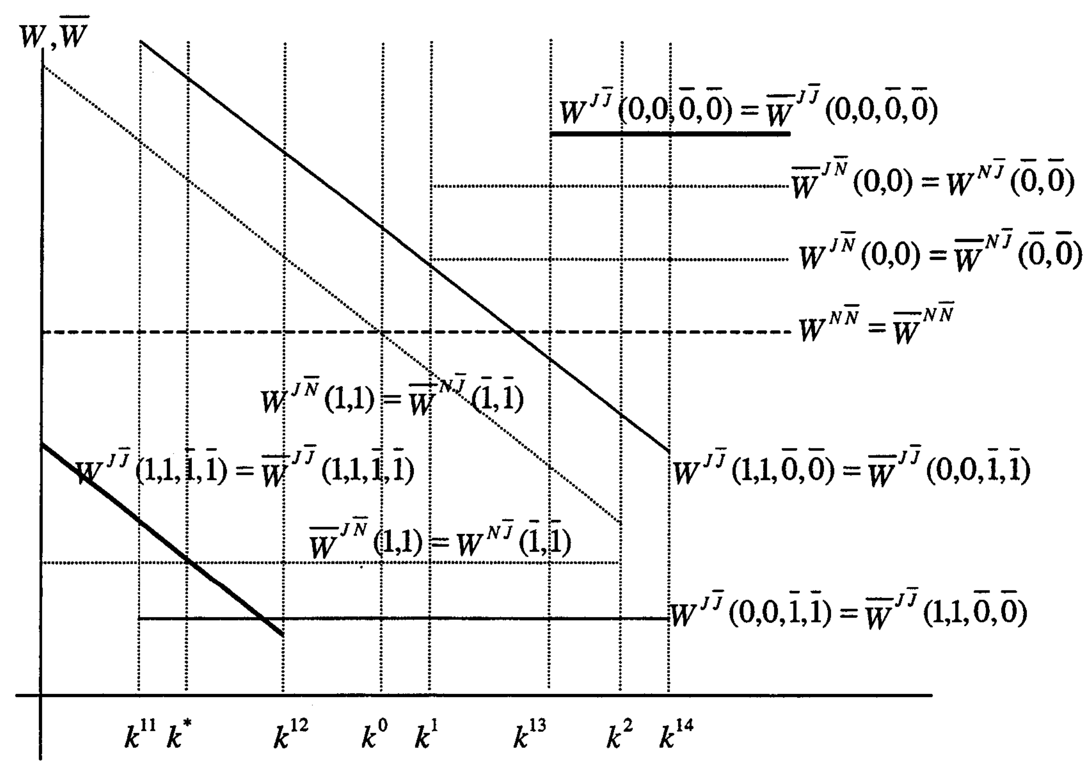

Figure 4.2 The welfare in the third market structure under the game $J\bar{J}$

However, for $k^* < k < k^{12}$ and the NE of spillovers $(1,1,\bar{1},\bar{1})$, the NEa of the policy game are (RJV, No RJV) and (No RJV, RJV) since $W^{J\bar{N}}(1,1) = \overline{W}^{N\bar{J}}(\bar{1},\bar{1}) > W^{N\bar{N}} = \overline{W}^{N\bar{N}}$ but $W^{J\bar{J}}(1,1,\bar{1},\bar{1}) < W^{N\bar{J}}(\bar{1},\bar{1})$, $\overline{W}^{J\bar{J}}(1,1,\bar{1},\bar{1}) < \overline{W}^{J\bar{N}J}(1,1)$ (see Table A2). We cannot predetermine which country allows an RJV formation. The implication is the country that allows an RJV formation is better off while the other country, which does not allow it, is worse off, compared to the game $N\bar{N}$. If both countries try to allow an RJV, then both will be hurt. If spillover costs lie between k^{11} and k^0, and the NE of spillovers under the game $J\bar{J}$ is $(1,1,\bar{0},\bar{0})$ or $(0,0,\bar{1},\bar{1})$, the NE of the policy game is (RJV, No RJV) or (No RJV, RJV), respectively (see Table A3). That is, for the NE $(1,1,\bar{0},\bar{0})$ the home country chooses 'Allow RJV' while the foreign country chooses 'Don't allow RJV', vice-versa for the NE $(0,0,\bar{1},\bar{1})$.

Suppose spillover costs lie between k^0 and k^1 (see Table A4); Then the NE of the policy game is (No RJV, No RJV). Neither country has an incentive to allow an RJV formation ($W^{J\bar{N}}(1,1) = \overline{W}^{N\bar{J}}(\bar{1},\bar{1}) < W^{N\bar{N}} = \overline{W}^{N\bar{N}}$). The spillover choice ($(1,1,\bar{0},\bar{0})$ or $(0,0,\bar{1},\bar{1})$) under the game $J\bar{J}$ does not matter in the governments' decision. This result holds for $k^1 < k < k^2$ if the NE of spillovers is (1,1) (or $\bar{1},\bar{1}$) in game $J\bar{N}$ (or $N\bar{J}$), and $(1,1,\bar{0},\bar{0})$ or $(0,0,\bar{1},\bar{1})$ in game $J\bar{J}$ (see Table A5). However, if the NE of spillovers is (0,0) (or $\bar{0},\bar{0}$) in game $J\bar{N}$ (or $N\bar{J}$), then the NE of the policy game is (RJV, No RJV) or (No RJV, RJV) (see Table A6). Each country has an incentive to allow its domestic firms to form an RJV ($W^{J\bar{N}}(0,0) = \overline{W}^{N\bar{J}}(\bar{0},\bar{0}) > W^{N\bar{N}} = \overline{W}^{N\bar{N}}$), if and only if the other country does not allow its firms to form an RJV ($W^{N\bar{J}}(\bar{0},\bar{0}) = W^{N\bar{J}}(0,0) > W^{J\bar{N}}(0,0) = \overline{W}^{N\bar{J}}(\bar{0},\bar{0})$). The result also holds for $k^2 < k < k^{14}$ if the NE(a) of spillovers are (0,0) (or $\bar{0},\bar{0}$) in game $J\bar{N}$ (or $N\bar{J}$) and $(1,1,\bar{0},\bar{0})$ or $(0,0,\bar{1},\bar{1})$ in game $J\bar{J}$ (see Table A6). Meanwhile, for $k^{13} < k < k^2$, if the NE(a) of spillovers are (1,1) (or $\bar{1},\bar{1}$) in game $J\bar{N}$ (or $N\bar{J}$) and $(0,0,\bar{0},\bar{0})$ or $(0,0,\bar{0},\bar{0})$ in game $J\bar{J}$, we have two NEa (see Table A7): (No RJV, No RJV) and (RJV, RJV). For any country, it is beneficial to choose the same strategy as the other country chooses

($W^{J\bar{N}}(0,0) = \overline{W}^{N\bar{J}}(\bar{0},\bar{0}) < W^{N\bar{N}} = \overline{W}^{N\bar{N}}$, $W^{J\bar{J}}(1,1,\bar{1},\bar{1}) = \overline{W}^{J\bar{J}}(1,1,\bar{1},\bar{1}) > W^{N\bar{J}}(\bar{0},\bar{0}) = W^{N\bar{J}}(0,0)$). Since $W^{J\bar{J}}(1,1,\bar{1},\bar{1}) = \overline{W}^{J\bar{J}}(1,1,\bar{1},\bar{1}) > W^{N\bar{N}} = W^{N\bar{N}}$, it is likely that both countries try to give a signal of choosing the strategy 'Allow RJV'.

Finally, for $k(> k^{14}) > k^{13}$, if the NE of spillovers is (0,0) (or $\bar{0},\bar{0}$) in game $J\bar{N}$ (or $N\bar{J}$) and $(0,0,\bar{0},\bar{0})$ in game $J\bar{J}$ (see Table A8), then the NE of the policy game is (RJV, RJV). Under this outcome both countries are better off, compared to the game $N\bar{N}$ ($W^{J\bar{J}}(0,0,\bar{0},\bar{0}) > W^{N\bar{N}}$, $\overline{W}^{J\bar{J}}(0,0,\bar{0},\bar{0}) > \overline{W}^{N\bar{N}}$). Given that the other country allows an RJV, any country makes a welfare improvement even if it does not allow, and its welfare exceeds that in the country where an RJV is formed ($W^{N\bar{J}}(\bar{0},\bar{0}) > W^{J\bar{N}}(0,0) > W^{N\bar{N}}$, $\overline{W}^{J\bar{N}}(0,0) > \overline{W}^{N\bar{J}}(\bar{0},\bar{0}) > \overline{W}^{N\bar{N}}$). However, since $W^{J\bar{J}}(0,0,\bar{0},\bar{0}) > W^{N\bar{J}}(\bar{0},\bar{0})$ and $\overline{W}^{J\bar{J}}(0,0,\bar{0},\bar{0}) > \overline{W}^{N\bar{J}}(\bar{0},\bar{0})$ both countries choose the strategy of 'Allow RJV'.

Lemma 3: Consider the third market structure. Then, a) if spillover costs are very low ($k < k^{11}$), both countries choose the strategy 'Allow RJV' under which they are worse off (prisoner's dilemma). b) If spillover costs are sufficiently high ($k > k^{14}$), both countries also choose the strategy 'Allow RJV' under which they are better off.

Proof: Note $W^{J\bar{J}}(1,1,\bar{1},\bar{1}) = \overline{W}^{J\bar{J}}(1,1,\bar{1},\bar{1})$, $W^{J\bar{J}}(0,0,\bar{0},\bar{0}) = \overline{W}^{J\bar{J}}(0,0,\bar{0},\bar{0})$, $W^{N\bar{N}} = \overline{W}^{N\bar{N}}$

a) $W^{J\bar{N}}(1,1) = \overline{W}^{N\bar{J}}(\bar{1},\bar{1}) > W^{N\bar{N}} = \overline{W}^{N\bar{N}}$ (see Lemma 1 and 2)

$$W^{J\bar{J}}(1,1,\bar{1},\bar{1}; k=0) - W^{N\bar{J}}(\bar{1},\bar{1}) = \frac{16\gamma(A-c)^2 g(\gamma)}{(25\gamma-24)^2(125\gamma^2-480\gamma+192)^2} \equiv 2k^*(> 2k^{11}) > 0$$

$$g(\gamma) \equiv 109375\gamma^4 - 840000\gamma^3 + 2160000\gamma^2 - 2580480\gamma + 995328$$

$$W^{J\bar{J}}(1,1,\bar{1},\bar{1}; k=0) - W^{N\bar{N}} = \frac{-16(A-c)^2\gamma\{625\gamma^2 + 2800\gamma - 1728\}}{(25\gamma-24)^2(25\gamma-8)^2} < 0$$

b) $W^{J\bar{N}}(0,0) > W^{N\bar{N}}$, $\overline{W}^{N\bar{J}}(\bar{0},\bar{0}) > \overline{W}^{N\bar{N}}$ (see Lemma 1 and 2)

$$W^{J\bar{J}}(0,0,\bar{0},\bar{0}) - W^{N\bar{J}}(\bar{0},\bar{0}) = \frac{20\gamma^2(A-c)^2(3125\gamma^3 - 12750\gamma^2 + 13500\gamma - 2664)}{(25\gamma-6)^2(125\gamma^2 - 210\gamma + 48)^2} > 0$$

$$W^{J\bar{J}}(0,0,\bar{0},\bar{0}) - W^{N\bar{N}} = \frac{100\gamma^2(A-c)^2(125\gamma-34)}{(25\gamma-6)^2(25\gamma-8)^2} > 0$$

4.5.2 An integrated market structure

In this subsection, we provide the welfare effects of the RJV in an integrated market. Since the home and foreign countries consume, unlike in the third market structure, we should examine how the RJV formation affects consumers in order to analyze welfare effects. The objective of the government is to maximize the domestic welfare, which is equal to the sum of firms' profits and consumer surplus ($W = \sum_i V_i + \alpha CS$, $\overline{W} = \sum_i \overline{V}_i + \overline{\alpha} CS$, where $i = 1,2$). $\alpha, \overline{\alpha} \in [0,1]$ denotes the consumption share of the home and foreign country, respectively. We assume that consumers in the two countries are identical, and that the consumption share is the same between the two countries for simplicity, i.e., $\alpha = \overline{\alpha} = 1/2$.[28] Thus, the consumer surplus for each country can be written by $\frac{1}{2}CS$, where $CS = \frac{(Q^*)^2}{2}$ is the total consumer surplus. In the integrated market structure, the objective of the government may not be identical to that of the firms because the government is also concerned about the effects of the RJV on consumer surplus. We show that many results obtained from the third market structure are reversed in the integrated market structure.

4.5.2.1 When only the home country allows an RJV formation

Consider the game $J\overline{N}$ where the home country allows its domestic firms to form an RJV while the foreign country does not. The welfare implications are analyzed for three domains of spillover costs ($k < k^1$, $k^1 < k < k^2$, $k > k^2$). Note that the payoff $(W, \overline{W})$ in each domain is determined by the home firms' choice on information sharing under the RJV.

[28] Allowing different consumption share between the two countries does not qualitatively change the results as long as the difference is not too big.

The Nash equilibrium(a) of spillovers (and R&D efforts) is $\beta_i = \beta_j = 1$ for $k < k^1$, $\beta_i = \beta_j = 0$, or $\beta_i = \beta_j = 1$ for $k^1 < k < k^2$, and $\beta_i = \beta_j = 0$ for $k > k^2$.

First, suppose that spillover costs are sufficiently high ($k > k^2$). Then, allowing an RJV formation hurts the home country, when compared to the game $N\overline{N}$ ($W^{J\overline{N}}(0,0) < W^{N\overline{N}}$). This is the opposite result from that obtained in the third market structure. The home firms' profits (domestic welfare in the third market case) are higher, compared to the game $N\overline{N}$, when the home country allows an RJV formation ($V^{J\overline{N}}(0,0) > V^{N\overline{N}}$). However, the consumers are hurt because the home firms' no information sharing under the RJV yields the increased market price ($P^{J\overline{N}}(0,0) > P^{N\overline{N}} \Leftrightarrow Q^{J\overline{N}}(0,0) < Q^{N\overline{N}}$). The increased firms' profits are overwhelmed by the consumer surplus loss ($2\left|V^{J\overline{N}}(0,0) - V^{N\overline{N}}\right| < \frac{1}{2}\left|CS^{J\overline{N}}(0,0) - CS^{N\overline{N}}\right|$). Therefore, the home government should not allow an RJV formation as long as spillover costs are sufficiently high.

Second, suppose that spillover costs lie in an intermediate level ($k^1 < k < k^2$). Then, the home firms under the RJV choose symmetric minimal or maximal spillovers. If symmetric minimal spillovers under the RJV are guaranteed, the home country is hurt. The same logic as the first case applies. However, if the home firms under the RJV choose maximal spillovers, then the home country experiences a welfare improvement, compared to the game $N\overline{N}$ ($W^{J\overline{N}}(1,1) > W^{N\overline{N}}$). This is exactly the opposite result as in the third market structure where the home firms' profits (thus welfare) decrease with the RJV formation ($V^{J\overline{N}}(1,1) < V^{N\overline{N}}$). The home firms' profits decrease even though their market share increases, by completely sharing information under the RJV, because the negative effects of spillover costs and the decreased market price dominate the increased market share effect on the firms' profits. The benefits in the home country come from the consumer gains, which result from the decreased market price ($P^{J\overline{N}}(1,1) < P^{N\overline{N}} \Leftrightarrow Q^{J\overline{N}}(1,1) > Q^{N\overline{N}}$). The consumer gains more than offset the decreased firms' profits ($2\left|V^{J\overline{N}}(1,1) - V^{N\overline{N}}\right| < \frac{1}{2}\left|CS^{J\overline{N}}(1,1) - CS^{N\overline{N}}\right|$). Therefore, the home government should allow an RJV formation only when the symmetric maximal spillovers under the RJV are chosen.

Lastly, suppose that spillover costs are sufficiently low ($k < k^1$). Then, the home country experiences welfare gains by allowing an RJV formation. Recall, in the third market structure, there exists another critical value of spillover costs ($k^0 < k^1$). We showed that $V^{J\overline{N}}(1,1) > V^{N\overline{N}}$ if $k < k^0$, but $V^{J\overline{N}}(1,1) < V^{N\overline{N}}$ if $k^0 < k < k^1$. Therefore, for $k < k^0$ it is obvious that the welfare of the home country increases, when compared to the game $N\overline{N}$, because the consumers make gains by the decreased market price ($CS^{J\overline{N}}(1,1) > CS^{N\overline{N}}$). Even if $k^0 < k < k^1$, the home country makes welfare gains by allowing an RJV formation because $2\left|V^{J\overline{N}}(1,1) - V^{N\overline{N}}\right| < \frac{1}{2}\left|CS^{J\overline{N}}(1,1) - CS^{N\overline{N}}\right|$. The policy implication is, as long as spillover costs are sufficiently low ($k < k^1$), the home government should allow its firms to form an RJV formation.

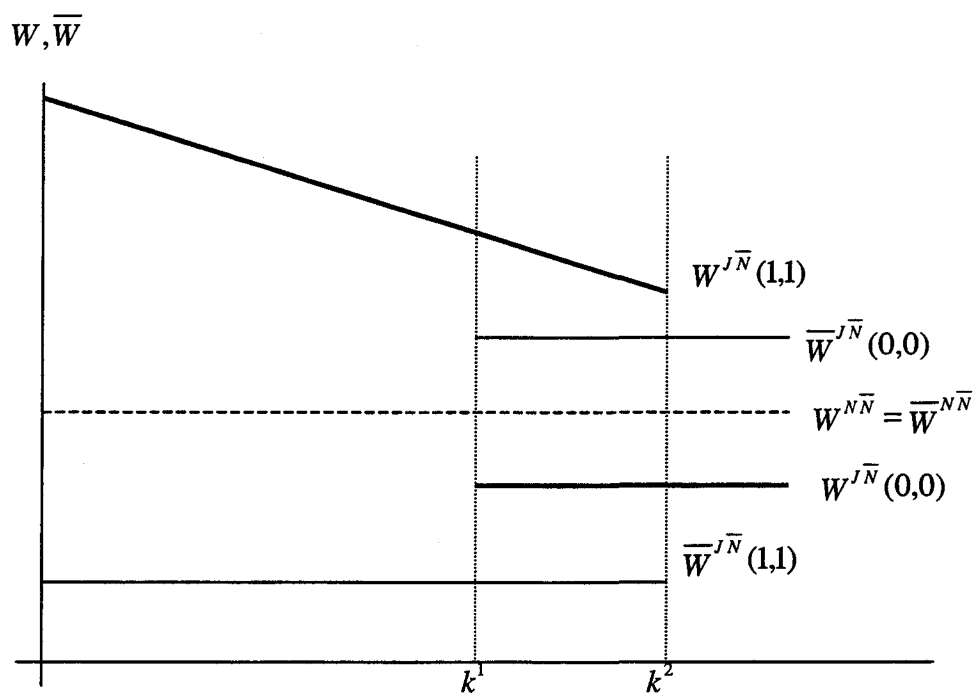

Figure 4.3 The welfare in the integrated market structure under the game $J\overline{N}$

As seen in figure 3, the foreign country is always hurt whenever the home firms achieve complete information sharing within an RJV. The foreign consumers are better off because of the decreased market price ($p^{J\bar{N}}(1,1) < p^{N\bar{N}}$). But, the foreign firms' profits decrease, when compared to the game $N\bar{N}$, because the home firms encroach on market share ($q^{J\bar{N}}(\beta^{J\bar{N}}=1) > q^{N\bar{N}} > \bar{q}^{J\bar{N}}(\beta^{J\bar{N}}=1)$). The decreased profits overwhelm the consumer gains ($2\left|\bar{V}^{J\bar{N}}(1,1) - \bar{V}^{N\bar{N}}\right| > \frac{1}{2}\left|CS^{J\bar{N}}(1,1) - CS^{N\bar{N}}\right|$). Meanwhile, the foreign country is better off whenever the home firms choose minimal spillovers under the RJV. The intuition is exactly the same as in the previous case, though the direction of change is reversed. The foreign consumers are worse off because of the decreased market price ($p^{J\bar{N}}(0,0) > p^{N\bar{N}}$). But, the foreign firms' profits increase, compared to the game $N\bar{N}$, because the market price increase, and also the foreign firms' market share increase ($\bar{q}^{J\bar{N}}(\beta^{J\bar{N}}=1) > q^{N\bar{N}} > q^{J\bar{N}}(\beta^{J\bar{N}}=1)$). The consumer losses are overwhelmed by the increased profits ($2\left|\bar{V}^{J\bar{N}}(1,1) - \bar{V}^{N\bar{N}}\right| > \frac{1}{2}\left|CS^{J\bar{N}}(1,1) - CS^{N\bar{N}}\right|$).

Lemma 4: Consider the integrated market structure. Suppose that only the home country allows an RJV formation. Then, a) the home (foreign) country is worse (better) off whenever the home firms choose minimal spillovers under the RJV. b) the home (foreign) country is better (worse) off whenever the home firms choose maximal spillovers.

Proof: a) $W^{J\bar{N}}(\beta_i = \beta_j = 0) - W^{N\bar{N}} = \dfrac{-20(A-c)^2\gamma^2\{3125\gamma^3 - 4375\gamma^2 - 1040\gamma + 576\}}{(125\gamma^2 - 210\gamma + 48)^2(25\gamma - 8)^2} < 0$

$$\bar{W}^{J\bar{N}}(\beta_i = \beta_j = 0) - \bar{W}^{N\bar{N}} = \frac{20(A-c)^2\gamma^2\{6250\gamma^3 - 15375\gamma^2 + 10800\gamma - 1984\}}{(125\gamma^2 - 210\gamma + 48)^2(25\gamma - 8)^2} > 0$$

b) $W^{J\bar{N}}(\beta_i = \beta_j = 1; k = 0) - W^{N\bar{N}} = \dfrac{16\gamma(A-c)^2 m(\gamma)}{(125\gamma^2 - 480\gamma + 192)^2(25\gamma - 8)^2} > 2k^2$, where

$$m(\gamma) \equiv \{171875\gamma^4 - 910000\gamma^3 + 1379200\gamma^2 - 691200\gamma + 110592\}$$

$$\overline{W}^{J\overline{N}}(\beta_i=\beta_j=1)-\overline{W}^{N\overline{N}}=\frac{-320\gamma^2(A-c)^2\{3125\gamma^3-19500\gamma^2+23040\gamma-5888}{(125\gamma^2-480\gamma+192)^2(25\gamma-8)^2}<0$$

4.5.2.2 When both countries have an incentive to allow an RJV in each country

In this sub-section, we identify the NE(a) of the policy game where both the home and the foreign countries simultaneously decide whether to allow an RJV or not, and provide the welfare implication of each NE. Recall that we have (0,0) (or $\bar{0},\bar{0}$) and (1,1) (or $\bar{1},\bar{1}$) in game $J\overline{N}$ (or $N\overline{J}$) while $(0,0,\bar{0},\bar{0})$, $(1,1,\bar{0},\bar{0})$, $(0,0,\bar{1},\bar{1})$, and $(1,1,\bar{1},\bar{1})$ in game $J\overline{J}$ for NE(a) of spillovers, and we identified the range of spillover costs for each NE of spillovers.

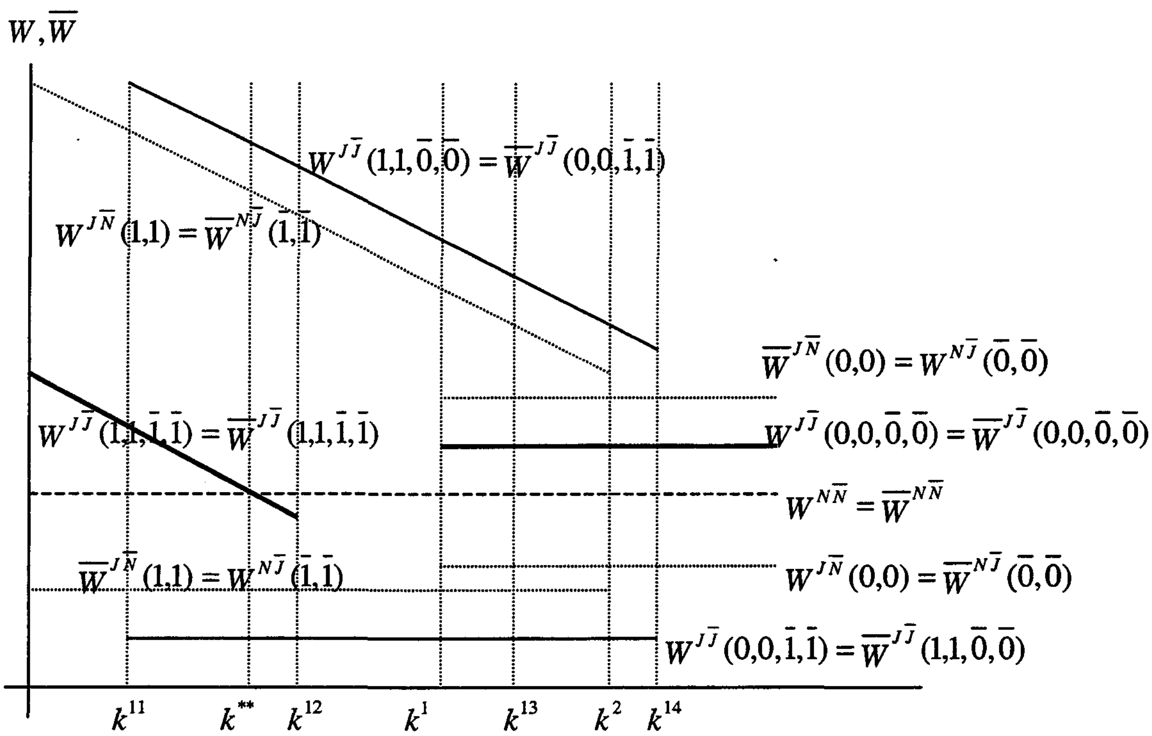

Figure 4.4 The welfare in the integrated market structure under the game $J\overline{J}$

Suppose spillover costs are very low, $k<k^{11}$ (see Table A9). Then, the NE of the policy game is (RJV, RJV) under which both countries are better off, compared to the game $N\overline{N}$ ($W^{J\overline{J}}(1,1,\bar{1},\bar{1})>W^{N\overline{N}}$, $\overline{W}^{J\overline{J}}(1,1,\bar{1},\bar{1})>\overline{W}^{N\overline{N}}$). This is exactly the opposite case as in the third market structure. The intuition is that firms' profits decrease due to the excessive competition between the two countries (RJVs), but consumer surplus increase because of the decreased market price. The increased consumer surplus dominates the decreased firms' profits ($2\left|V^{J\bar{N}}(1,1,\bar{1},\bar{1}) - V^{N\bar{N}}\right| = 2\left|\bar{V}^{J\bar{N}}(1,1,\bar{1},\bar{1}) - \bar{V}^{N\bar{N}}\right| < \frac{1}{2}\left|CS^{J\bar{N}}(1,1,\bar{1},\bar{1}) - CS^{N\bar{N}}\right|$). This result also holds for $k^{11} < k < k^{**}$ (where k^{**} satisfies that $W^{J\bar{J}}(1,1,\bar{1},\bar{1}; k = k^{**}) - W^{N\bar{N}} = 0$ or $\overline{W}^{J\bar{J}}(1,1,\bar{1},\bar{1}; k = k^{**}) - \overline{W}^{N\bar{N}} = 0$) if the NE of spillovers is $(1,1,\bar{1},\bar{1})$ in game $J\bar{J}$ (see Table A9). However, for $k^{**} < k < k^{12}$ and the NE of spillovers $(1,1,\bar{1},\bar{1})$, the policy game leads to a prisoner's dilemma result (see Table A10). The NE of the policy game is (RJV, RJV). Both countries are worse off ($W^{J\bar{J}}(1,1,\bar{1},\bar{1}) < W^{N\bar{N}}$, $\overline{W}^{J\bar{J}}(1,1,\bar{1},\bar{1}) < \overline{W}^{N\bar{N}}$), but each country has an incentive to allow an RJV ($W^{J\bar{N}}(1,1) = \overline{W}^{N\bar{J}}(\bar{1},\bar{1}) > W^{N\bar{N}} = \overline{W}^{N\bar{N}} > W^{N\bar{J}}(\bar{1},\bar{1}) = \overline{W}^{J\bar{N}}(\bar{1},\bar{1})$). This sharply contrasts with Motta's result (1996) that both the home and foreign countries always improve their domestic welfare in the integrated market structure by the RJV formation in each country.

Meanwhile, for $k^{11} < k < k^{1}$ and the NE of spillovers $(1,1,\bar{0},\bar{0})$ and $(0,0,\bar{1},\bar{1})$ in game $J\bar{J}$, the NE of the policy game is (RJV, No RJV) and (No RJV, RJV), respectively (see Table A11). The country which allows an RJV formation is better off, compared to the game $N\bar{N}$, while the other country, which does not allow its domestic firms to form an RJV, is worse off ($W^{J\bar{N}}(1,1) = \overline{W}^{N\bar{J}}(\bar{1},\bar{1}) > W^{N\bar{N}} = \overline{W}^{N\bar{N}} > W^{N\bar{J}}(\bar{1},\bar{1}) = \overline{W}^{J\bar{N}}(1,1)$). This result also holds for $k^{1} < k < k^{2}$ if the NE of spillover are (1,1) (or $\bar{1},\bar{1}$) in game $J\bar{N}$ (or $N\bar{J}$), and $(1,1,\bar{0},\bar{0})$ or $(0,0,\bar{1},\bar{1})$ in game $J\bar{J}$.

For $k(> k^{14}) > k^{1}$, if the NE of spillovers is (0,0) (or $\bar{0},\bar{0}$) in game $J\bar{N}$ (or $N\bar{J}$), the NE of the policy game is (No RJV, No RJV) regardless of the NE of spillovers in game $J\bar{J}$ (see Table A12). This is because neither country has an incentive to allow an RJV ($W^{J\bar{N}}(0,0) = \overline{W}^{N\bar{J}}(\bar{0},\bar{0}) < W^{N\bar{N}} = \overline{W}^{N\bar{N}} < W^{N\bar{J}}(\bar{0},\bar{0}) = \overline{W}^{J\bar{N}}(0,0)$). One thing to note is that the NE (No RJV, No RJV) is welfare inferior to the NE of spillovers (0,0) (or $\bar{0},\bar{0}$) in game $J\bar{N}$

(or $N\bar{J}$) and $(0,0,\bar{0},\bar{0})$ in game $J\bar{J}$ ($W^{J\bar{J}}(0,0,\bar{0},\bar{0}) > W^{N\bar{N}}$, $\overline{W}^{J\bar{J}}(0,0,\bar{0},\bar{0}) > \overline{W}^{N\bar{N}}$).

Lemma 5: Consider the integrated market structure. Then, a) if spillover costs are very low ($k < k^{11}$), both countries choose the strategy 'Allow RJV' under which they are better off. b) If spillover costs are sufficiently high ($k > k^{14}$), both countries choose the strategy 'Don't allow RJV', which is a welfare inferior outcome.

Proof: a) $W^{J\bar{N}}(1,1) = \overline{W}^{N\bar{J}}(\bar{1},\bar{1}) > W^{N\bar{N}} = \overline{W}^{N\bar{N}} > W^{N\bar{J}}(\bar{1},\bar{1}) = \overline{W}^{J\bar{N}}(\bar{1},\bar{1})$ (see Proposition 4)

$$W^{J\bar{J}}(1,1,\bar{1},\bar{1};k=0) - W^{N\bar{J}}(\bar{1},\bar{1}) = \frac{16\gamma(A-c)^2(6875\gamma^3 - 49000\gamma^2 + 93120\gamma - 41472)}{(25\gamma-24)^2(125\gamma^2 - 480\gamma + 192)^2} > 2k^{11}$$

$$W^{J\bar{J}}(1,1,1,1;k=0) - W^{N\bar{N}} = \frac{16\gamma(A-c)^2(175\gamma-72)}{\{25\gamma-24\}^2(25\gamma-8)^2} \equiv 2k^{**} > 2k^{11}$$

b) $W^{J\bar{N}}(0,0) = \overline{W}^{N\bar{J}}(\bar{0},\bar{0}) < W^{N\bar{N}} = \overline{W}^{N\bar{N}} < W^{N\bar{J}}(\bar{0},\bar{0}) = \overline{W}^{J\bar{N}}(\bar{0},\bar{0})$ (see Proposition 4)

$$W^{J\bar{J}}(0,0,\bar{0},\bar{0}) - W^{N\bar{J}}(\bar{0},\bar{0}) = \frac{20\gamma^2(A-c)^2(250\gamma^2 - 465\gamma + 126)}{(25\gamma-6)^2(125\gamma^2 - 210\gamma + 48)^2} > 0$$

$$W^{J\bar{J}}(0,0,0,0) - W^{N\bar{N}} = \frac{100(A-c)^2\gamma^2}{(25\gamma-6)^2(25\gamma-8)^2} > 0$$

4.6 Conclusions

This chapter examines the role of RJV (or R&D cooperation) in the presence of international competition. Unlike previous studies where information sharing within an RJV is treated as exogenous, we allow it to be determined endogenously. The main questions are whether firms under the RJV choose to completely share their information, and whether any government should allow its domestic firms to form an RJV to maximize total welfare. Regarding the first question, we show that firms under the RJV do not share any information if spillover costs are sufficiently high while they choose maximal spillovers within an RJV if spillover costs are sufficiently low. The minimal spillovers within an RJV are chosen due to the anticompetitive reasons. This result contrasts with previous studies where complete information sharing within an RJV is usually assumed. We also find that multiple Nash equilibria may exist. Under the game $J\overline{N}$, symmetric minimal and maximal spillovers are chosen within an RJV when spillover costs lie in an intermediate range ($k^1 < k < k^2$). Meanwhile, under the game $J\overline{J}$, symmetric minimal (0,0,0,0) and asymmetric spillovers ((1,1,0,0) or (0,0,1,1)) or symmetric maximal (1,1,1,1) and asymmetric spillovers ((1,1,0,0) or (0,0,1,1)) between the two countries (RJVs) turn out to be the Nash equilibria for a moderate range of spillover costs ($k^{11} < (k^1) < k < (k^2) < k^{14}$).

To provide the answer as to whether any government should allow its domestic firms to form an RJV to maximize total welfare, we consider two final markets: a 'third market' and an integrated market. We show that many results obtained in the third market structure become reversed in the integrated market structure. For example, consider the case where only the home country allows an RJV formation while the foreign country does not. If spillover costs are sufficiently high ($k > k^2$), allowing an RJV benefits the home country in the third market, but it hurts the home country in the integrated market. It is basically due to the home firms' choice of spillovers under the RJV. They choose symmetric minimal spillovers, which yields the increased final market price. The home firms' profits increase, but the consumer surplus decreases. The consumer loss dominates the increased home firms' profits. If spillover costs lie in an intermediate range ($k^1 < k < k^2$), the home country is better off only under the outcome ($\beta_i = \beta_j = 0$) in the third market, but only under the outcome ($\beta_i = \beta_j = 1$) in the integrated market. Lastly, suppose that spillover costs are sufficiently low ($k < k^1$). Then, it is always beneficial for the home country to allow an RJV formation in the integrated market structure. Meanwhile, there exists a critical value of spillover costs $k^0 (< k^1)$ in the third market structure such that the home country is better off only if $k < k^0$.

We also identify the NE(a) of the policy game where both the home and the foreign countries simultaneously decide whether to allow an RJV or not, and investigate the welfare implications when both the home and foreign countries allow an RJV formation in each country. First, consider the third market structure. If spillover costs are very low ($k < k^{11}$), the NE of the policy game is (RJV, RJV), but under this outcome both countries are hurt, which leads to a prisoner's dilemma result. The excessive R&D competition between the two countries (RJVs), by completely sharing information within an RJV, yields the increased market share, but the decreased market price. The negative effects of spillover costs and the decreased market price dominate the increased market share effect on the firms' profits. Meanwhile, if spillover costs are sufficiently high ($k > k^{14}$), then the NE of the policy game is (RJV, RJV), and under this outcome both countries are better off, compared to the R&D non-cooperation game ($N\overline{N}$). If spillover costs are between k^{11} and k^{14}, it may be a little bit complex to provide policy implications since we have multiple NE(a) of the policy game, which are basically due to multiple NEa of spillovers both in game $J\overline{N}$ (or $N\overline{J}$) and game $J\overline{J}$. However, given that the NE is identified, it is straightforward to provide the welfare implications for each NE.

Some different results are obtained in the integrated market structure. If spillover costs are very low ($k < k^{11}$), the NE of the policy game is (RJV, RJV). Under this outcome both countries are better off, which is opposite to the results in the third market structure. It is because, even though the firms are hurt by the excessive R&D competition, the consumer gains due to the decreased market price overwhelm the firms' losses. Meanwhile, if spillover costs are sufficiently high ($k > k^{14}$), then the NE of the policy game is (No RJV, NO RJV). This outcome is welfare inferior in the sense that both countries can make welfare gains if they choose the strategy 'Allow RJV'.

There are some possible extensions of this chapter. The first extension is to check the results obtained in the paper with the general functional forms. As mentioned above, the corner solution of spillovers is due to the assumption of linear spillover costs while we can get partial spillovers with a quadratic form of spillover costs. Thus, to get more meaningful and robust results, it is necessary to check the ideas in this chapter with more general functional forms. The second idea is to introduce asymmetric spillover costs among firms, which may be more realistic in the sense that the firms are likely to differ in the ability to absorb or assimilate their rivals' knowledge. Also, introducing involuntary spillovers between intra-country and inter-country may help examine the robustness of the results obtained by Steurs (1997). The third idea is to consider an alternative decision rule for the RJV. The literature uniformly assumes joint profit maximization, and focuses on the effect of information sharing under the RJV. Introducing cost sharing and risk sharing for the RJV and assuming own profit maximization may be more reasonable. Finally, examining the optimal number of RJVs in an industry and checking whether there may be any optimal policy (subsidy or tax) on R&D cooperation (RJV formation) may be necessary studies.

Appendix A. Critical values of spillover costs

$$k^1 \equiv V_i(1,0,k=0) - V_i(0,0) = \frac{12\gamma(A-c)^2 I_1(\gamma)}{(125\gamma^3 - 470\gamma^2 + 420\gamma - 96)^2(125\gamma^2 - 210\gamma + 48)^2}$$

$$I_1(\gamma) = 2734375\gamma^8 - 22921875\gamma^7 + 80455000\gamma^6 + 153625000\gamma^5 - 1735062\gamma^4$$
$$-11796736\gamma^3 + 46949376\gamma^2 - 10027008\gamma + 884736$$

$$k^2 \equiv V_i(1,1,k=0) - V_i(0,1) = \frac{12\gamma(A-c)^2 I_2(\gamma)}{(125\gamma^3 - 470\gamma^2 + 420\gamma - 96)^2(125\gamma^2 - 480\gamma + 192)^2}$$

$$I_2(\gamma) = 2734375\gamma^7 + 167356250\gamma^6 - 44580500\gamma^5 + 688615200\gamma^4 - 629081600\gamma^3$$
$$+331616256\gamma^2 - 92749824\gamma + 10616832$$

$$k^{11} \equiv V_i(1,0,1,1;k=0) - V_i(0,0,1,1) \equiv V_j(0,1,1,1;k=0) - V_j(0,0,1,1)$$
$$\equiv \overline{V}_i(1,1,1,0;k=0) - \overline{V}_i(1,1,0,0) \equiv \overline{V}_j(1,1,0,1;k=0) - \overline{V}_j(1,10,0)$$
$$= \frac{12\gamma(A-c)^2 \Phi_1(\gamma)}{(125\gamma^3 - 710\gamma^2 + 900\gamma - 288)^2(125\gamma^2 - 450\gamma + 144)^2}$$

$$\Phi_1(\gamma) \equiv 2734375\gamma^8 - 49421875\gamma^7 + 356535000\gamma^6 - 1317081000\gamma^5 + 2675323800\gamma^4$$
$$-3017571840\gamma^3 + 1842103296\gamma^2 - 573308928\gamma + 71663616$$

$$k^{12} \equiv V_i(1,1,1,1;k=0) - V_i(0,1,1,1) \equiv V_j(1,1,1,1;k=0) - V_i(1,0,1,1)$$
$$\equiv \overline{V}_i(1,1,1,1;k=0) - \overline{V}_i(1,1,0,1) \equiv \overline{V}_j(1,1,1,1;k=0) - \overline{V}_j(1,11,,0)$$
$$= \frac{12\gamma(A-c)^2 \Phi_2(\gamma)}{(125\gamma^3 - 710\gamma^2 + 900\gamma - 288)^2(25\gamma - 24)^2}$$

$$\Phi_2(\gamma) \equiv 109375\gamma^6 - 1346875\gamma^5 + 6145050\gamma^4 - 13119540\gamma^3 + 14160096\gamma^2$$
$$-7444224\gamma + 1492992$$

$$k^{13} \equiv V_i(1,0,0,0;k=0) - V_i(0,0,0,0) \equiv V_j(0,1,0,0;k=0) - V_i(0,0,0,0)$$
$$\equiv \overline{V}_i(0,0,1,0;k=0) - \overline{V}_i(0,0,0,0) \equiv \overline{V}_j(0,0,0,1;k=0) - \overline{V}_j(0,0,0,0)$$
$$= \frac{12\gamma(A-c)^2 \Phi_3(\gamma)}{(125\gamma^3 - 440\gamma^2 + 360\gamma - 72)^2(25\gamma - 6)^2}$$

$$\Phi_3(\gamma) \equiv 109375\gamma^6 - 521875\gamma^5 + 949800\gamma^4 - 846660\gamma^3 + 389016\gamma^2 - 88128\gamma + 7776$$

$$k^{14} \equiv V_i(1,1,0,0;k=0) - V_i(0,1,0,0) \equiv V_j(1,1,0,0;k=0) - V_i(1,0,0,0)$$

$$\equiv \overline{V}_i(0,0,1,1;k=0) - \overline{V}_i(0,0,0,1) \equiv \overline{V}_j(0,0,1,1;k=0) - \overline{V}_j(0,0,1,0)$$

$$= \frac{12\gamma(A-c)^2\Phi_4(\gamma)}{(125\gamma^3 - 440\gamma^2 + 360\gamma - 72)^2(125\gamma^2 - 450\gamma + 144)^2}$$

$$\Phi_4(\gamma) \equiv 2734375\gamma^8 - 30109375\gamma^7 + 133841250\gamma^6 - 312121500\gamma^5 + 417520800\gamma^4$$
$$- 327825360\gamma^3 + 147518496\gamma^2 - 34945344\gamma + 3359232$$

$$k^0 \equiv V^{J\overline{N}}(\beta_i = \beta_j = 1, k=0) - V^{N\overline{N}} = \frac{8\gamma(A-c)^2 f_0(\gamma)}{\{125\gamma^2 - 480\gamma + 192\}^2(25\gamma - 8)^2}$$

$$f_0(\gamma) \equiv 109375\gamma^4 - 580000\gamma^3 + 931200\gamma^2 - 563200\gamma + 110592$$

$$k^* \equiv V^{J\overline{J}}(1,1,\bar{1},\bar{1};k=0) - V^{N\overline{J}}(\bar{1},\bar{1}) = \frac{8\gamma(A-c)^2 f_1(\gamma)}{(25\gamma - 24)^2(125\gamma^2 - 480\gamma + 192)^2}$$

$$f_1(\gamma) \equiv 109375\gamma^4 - 840000\gamma^3 + 2160000\gamma^2 - 2580480\gamma + 995328$$

$$k^{**} \equiv \frac{1}{2}\{2V^{J\overline{J}}(1,1,\bar{1},\bar{1};k=0) + \frac{1}{2}CS^{J\overline{J}}(1,1,\bar{1},\bar{1})\} - \frac{1}{2}\{2V^{N\overline{N}} + \frac{1}{2}CS^{N\overline{N}}\}$$

$$= \frac{8\gamma(A-c)^2(175\gamma - 72)}{\{25\gamma - 24\}^2(25\gamma - 8)^2}$$

Appendix B. NE(a) of the policy game: Numerical example ($\gamma = 5$, $A - c = 10$)

Each table describes payoff (Home welfare, Foreign welfare) for the policy game between the home and the foreign countries. The payoff depends on the domain of spillover costs and the NE of spillover costs both in game $J\bar{N}$ (or $N\bar{J}$) and in game $J\bar{J}$. The bold letter in each table denotes the NE of the policy game.

<Third market>

Table A1. $k < (k^{11}) < k^{*} \equiv 2.5425$, $(1,1)$ (or $\bar{1},\bar{1}$) in $J\bar{N}$ (or $N\bar{J}$), $(1,1,\bar{1},\bar{1})$ in $J\bar{J}$.

	Don't allow RJV	Allow RJV
Don't allow RJV	(6.7938, 6.7938)	(0.1106, 18.215-2k)
Allow RJV	(18.215-2k, 0.1106)	**(5.1956-2k, 5.1956-2k)**

Table A2. $2.5425 \equiv k^{*} < k < k^{12} \equiv 2.56416$, $(1,1)$ (or $\bar{1},\bar{1}$) in $J\bar{N}$ (or $N\bar{J}$), $(1,1,\bar{1},\bar{1})$ in $J\bar{J}$.

	Don't allow RJV	Allow RJV
Don't allow RJV	(6.7938, 6.7938)	**(0.1106, 18.215-2k)**
Allow RJV	**(18.215-2k, 0.1106)**	(5.1956-2k, 5.1956-2k)

Table A3. $0.20048 \equiv k^{11} < k < k^{0} \equiv 5.7106$, $(1,1)$ (or $\bar{1},\bar{1}$) in $J\bar{N}$ (or $N\bar{J}$), $(1,1,\bar{0},\bar{0})$ in $J\bar{J}$.

	Don't allow RJV	Allow RJV
Don't allow RJV	(6.7938, 6.7938)	(0.1106, 18.215-2k)
Allow RJV	**(18.215-2k, 0.1106)**	(18.426-2k, 0.10305)

Table A4. $5.7106 \equiv k^{0} < k < k^{1} \equiv 5.7464$, $(1,1)$ (or $\bar{1},\bar{1}$) in $J\bar{N}$ (or $N\bar{J}$), $(1,1,\bar{0},\bar{0})$ in $J\bar{J}$.

	Don't allow RJV	Allow RJV
Don't allow RJV	**(6.7938, 6.7938)**	(0.1106, 18.215-2k)
Allow RJV	(18.215-2k, 0.1106)	(18.426-2k, 0.10305)

Table A5. $5.7464 \equiv k^1 < k < k^2 \equiv 7.8826$, $(1,1)$ (or $\bar{1},\bar{1}$) in $J\bar{N}$ (or $N\bar{J}$), $(1,1,\bar{0},\bar{0})$ in $J\bar{J}$.

	Don't allow RJV	Allow RJV
Don't allow RJV	**(6.7938, 6.7938)**	(0.1106, 18.215-2k)
Allow RJV	(18.215-2k, 0.1106)	(18.426-2k, 0.10305)

Table A6. $5.7464 \equiv k^1 < k < k^{14} \equiv 7.9028$, $(0,0)$ (or $\bar{0},\bar{0}$) in $J\bar{N}$ (or $N\bar{J}$), $(1,1,\bar{0},\bar{0})$ in $J\bar{J}$.

	Don't allow RJV	Allow RJV
Don't allow RJV	(6.7938, 6.7938)	**(7.4489, 6.8609)**
Allow RJV	**(6.8609, 7.4489)**	(18.426-2k, 0.10305)

Table A7. $6.0384 \equiv k^{13} < k < k^2 \equiv 7.8826$, $(1,1)$ (or $\bar{1},\bar{1}$) in $J\bar{N}$ (or $N\bar{J}$), $(0,0,\bar{0},\bar{0})$ in $J\bar{J}$.

	Don't allow RJV	Allow RJV
Don't allow RJV	**(6.7938, 6.7938)**	(0.1106, 18.215-2k)
Allow RJV	(18.215-2k, 0.1106)	**(7.556, 7.556)**

Table A8. $k(>k^{14}) > k^{13} \equiv 6.0384$, $(0,0)$ (or $\bar{0},\bar{0}$) in $J\bar{N}$ (or $N\bar{J}$), $(0,0,\bar{0},\bar{0})$ in $J\bar{J}$.

	Don't allow RJV	Allow RJV
Don't allow RJV	(6.7938, 6.7938)	(7.4489, 6.8609)
Allow RJV	(6.8609, 7.4489)	**(7.556, 7.556)**

<Integrated market>

Table A9. $k(<k^{11}) < k^{**} \equiv 2.323$, $(1,1)$ (or $\bar{1},\bar{1}$) in $J\bar{N}$ (or $N\bar{J}$), $(1,1,\bar{1},\bar{1})$ in $J\bar{J}$.

	Don't allow RJV	Allow RJV
Don't allow RJV	(25.057, 25.057)	(24.192, 42.297-2k)
Allow RJV	(42.297-2k, 24.192)	**(29.703-2k, 29.703-2k)**

Table A10. $0.20048 \equiv k^{11} < k < k^{12} \equiv 2.56416$, $(1,1)$ (or $\bar{1},\bar{1}$) in $J\bar{N}$ (or $N\bar{J}$), $(1,1,\bar{1},\bar{1})$ in $J\bar{J}$

	Don't allow RJV	Allow RJV
Don't allow RJV	(25.057, 25.057)	(24.192, 42.297-2k)
Allow RJV	(42.297-2k, 24.192)	**(29.703-2k, 29.703-2k)**

Table A11. $0.20048 \equiv k^{11} < k < k^{2} \equiv 7.8826$, $(1,1)$ (or $\bar{1},\bar{1}$) in $J\bar{N}$ (or $N\bar{J}$), $(1,1,\bar{0},\bar{0})$ in $J\bar{J}$ [1]

	Don't allow RJV	Allow RJV
Don't allow RJV	(25.057, 25.057)	(24.192, 42.297-2k)
Allow RJV	**(42.297-2k, 24.192)**	(42.503-2k, 24.179)

Table A12. $5.7464 \equiv k^{1} < k < k^{14} \equiv 7.9028$, $(0,0)$ (or $\bar{0},\bar{0}$) in $J\bar{N}$ (or $N\bar{J}$), $(1,1,\bar{0},\bar{0})$ in $J\bar{J}$.

	Don't allow RJV	Allow RJV
Don't allow RJV	**(25.057, 25.057)**	(25.42, 24.832)
Allow RJV	(24.832, 25.42)	(42.503-2k, 24.179)

Table A13. $k > k^{1} \equiv 5.7464$, $(0,0)$ (or $\bar{0},\bar{0}$) in $J\bar{N}$ (or $N\bar{J}$), $(0,0,\bar{0},\bar{0})$ in $J\bar{J}$. [2]

	Don't allow RJV	Allow RJV
Don't allow RJV	**(25.057, 25.057)**	(25.42, 24.832)
Allow RJV	(24.832, 25.42)	(25.21, 25.21)

[1] For $(0,0,\bar{1},\bar{1})$, the NE of the policy game is (Home: No RJV, Foreign: RJV)

[2] The NE (No RJV, No RJV) is welfare inferior since $W^{N\bar{N}} < W^{J\bar{J}}$, $\overline{W}^{N\bar{N}} < \overline{W}^{J\bar{J}}$

CHAPTER 5. GENERAL CONCLUSION

5.1 Summary

This dissertation consists of three essays investigating the welfare implications of R&D policies in the presence of spillovers. The research joint venture (RJV) formation and intellectual property rights (IPR) protection are considered as tools of R&D policies. The first essay (chapter 2) investigates the policy implications of an RJV. Unlike previous studies, the degree of spillovers (information sharing) within an RJV is determined endogenously. We assume that the RJV is costly in the sense that firms incur two kinds of costs: RJV formation costs and spillover costs. We find that firms within an RJV do not share any information if spillover costs are sufficiently high, and that private interests with an RJV are not consistent with public interests for a wide range of parameter values. The main policy implications are as follows. First, if spillover costs are sufficiently high but the degree of involuntary spillovers is sufficiently low, then the government should discourage firms from joining in an RJV for relatively low RJV formation costs. However, it does not have to implement any policy for relatively high RJV formation costs since private and public interests are consistent. Second, if both spillover costs and the degree of involuntary spillovers are sufficiently high, then government intervention is unnecessary for very low or very high RJV formation costs, while it should encourage firms to join in an RJV for median RJV formation costs. Finally, when spillover costs are sufficiently low, the same results as in the second case are obtained, but it is shown that the critical value of RJV formation costs is different.

The second essay (chapter 3) examines the welfare effects of intellectual property rights (IPR) protection in the north-south trade context. We ask which southern countries, if any, should provide more IPR protection, assuming that the differentiated IPR protection among southern countries can be made through a WTO agreement. We consider a situation where only the northern country innovates, and n-1 southern countries have different capacities to absorb knowledge spillovers from the northern innovations. The spillover share, which is defined as the spillovers in any country divided by the sum of spillovers for all countries, plays a crucial role in determining the welfare effects of IPR protection. Some findings obtained in this essay are as follows. The spillover expansion from relaxed IPR protection in any southern country may or may not reduce the unit production cost, depending on the spillover share. The profit of the firm always increases whenever its unit production cost decreases with spillovers. There is a possibility that the profit effect of spillovers is also positive even when it raises unit production costs. This happens when the R&D efficiency of the northern firm is sufficiently low or if the spillover share is not too big. Meanwhile, the effects of relaxed IPR protection in any southern country on aggregate output and consumer surplus are negative unless the sum of spillovers is relatively small and the R&D efficiency is very low.

The welfare effects of spillovers depend on both the consumption share and the spillover share. The southern countries can be classified into three groups in terms of welfare effects of spillovers. The countries in the first group are better off from relaxed IPR protection both in their own countries and in the other countries. The countries in the second group are better off from spillovers in their country, but worse off from spillovers in the other group. The third group suffers from welfare loss when IPR protection is relaxed in any southern country.

The last essay (chapter 4) combines the analysis of the R&D cooperation with the strategic trade policy theory. It investigates the role of RJV (or R&D cooperation) in the presence of international competition. We endogenize spillovers (information sharing) within an RJV, and assume that firms must incur costs to increase the amounts of information sharing. Many results obtained in the third market structure become reversed in the integrated market structure. In the situation where only the home country allows an RJV formation while the foreign country does not, if spillover costs are sufficiently high, allowing an RJV benefits the home country in the third market, but it hurts the home country in the integrated market. It is basically due to the home firms' choice of spillovers under the RJV. They choose symmetric minimal spillovers, which yields the increased final market price. The home firms' profits increase, but the consumer surplus decreases. The consumer loss dominates the increased home firms' profits. If spillover costs lie in an intermediate range, the home country is better off only under the outcome of minimal spillovers within an RJV in the third market, but only under the outcome of maximal spillovers within an RJV in the integrated market case. Meanwhile, as long as spillover costs are very low, allowing an RJV is always beneficial for the home country both in the third market and integrated market structure.

We also identify the NE(a) of the policy game where both the home and the foreign countries simultaneously decide whether to allow an RJV or not, and investigate the welfare implications. In the third market structure, if spillover costs are very low, the NE of the policy game is (RJV, RJV), but under this outcome both countries are hurt, which leads to a prisoner's dilemma result. The excessive R&D competition between the two countries (RJVs), by completely sharing information within an RJV, yields the increased market share, but the decreased market price. The negative effects of spillover costs and the decreased market price dominate the increased market share effect on the firms' profits. Meanwhile, if spillover costs are sufficiently high, then the NE of the policy game is (RJV, RJV), and under this outcome both countries are better off, compared to the R&D non-cooperation game. Some different results are obtained in the integrated market structure. If spillover costs are very low, the NE of the policy game is (RJV, RJV). Under this outcome both countries are better off, which is opposite to the results in the third market structure. It is because, even though the firms are hurt by the excessive R&D competition, the consumer gains due to the decreased market price overwhelm the firms' losses. Meanwhile, if spillover costs are sufficiently high, then the NE of the policy game is (No RJV, No RJV). This outcome is welfare inferior in the sense that both countries can make welfare gains if they choose the strategy 'Allow RJV'.

5.2 Suggestions for future research

Following the literature we assumed joint profit maximization under the RJV. However, whether this assumption is appropriate requires further analysis since it is difficult to believe that firms can write the contracts to maximize joint profits especially when they are competitors in a final market. Also, the profit per firm under the RJV is likely to depend on its own R&D spending. Then, it may be more profitable for the firm to deviate from joint profit maximization by maximizing its own profit, choosing own R&D spending. Thus, it is worthwhile to study the relevancy of 'joint profit maximization' assumption under the RJV.

One implicit assumption we made in chapter 2 and chapter 3 is that R&D outcomes of one firm are always beneficial for the other if firms can share information completely. However, each firm may pursue different research projects, thus the nature of final R&D outcomes may also differ across firms. Therefore, the amounts that each firm absorbs in knowledge spillovers may depend on whether these outcomes are substitutable or complimentary. Introducing different R&D outcomes is obviously more realistic, and it may help us understand the role of information sharing.

It is hard to believe that technologies that the northern firm produces are always appropriate for the use of all southern countries. Thus, it is worthwhile to extend the issue of IPR protection (chapter 3) by introducing appropriate technology for southern countries. Also, the direct extension of chapter 3 would include investigating optimal patent policy in terms of domestic welfare or how to reach an agreement on IPR protection that is Pareto improving. Meanwhile, one extension of chapter 4 could include the analysis of the optimal number of RJVs in an industry, and the comparison of RJV with R&D subsidy or tax may be interesting. Finally, the models in each essay are very specific, and we need to check the robustness of the results with more general functional forms.

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